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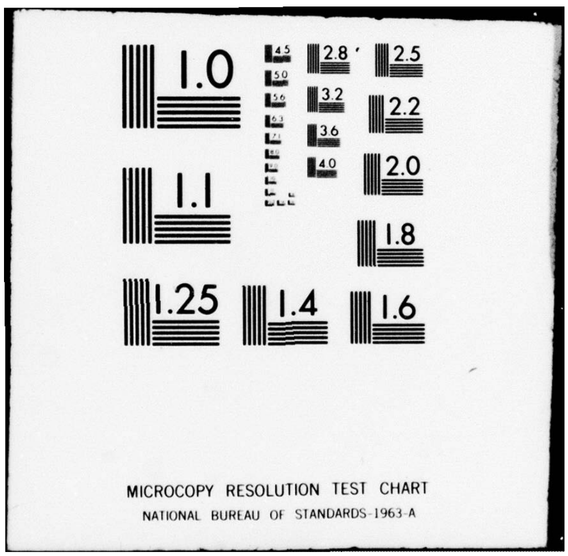
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A SHIPBOARD MACHINERY PERFORMANCE MONITORING SYSTEM CONCEPT

A SHIPBOARD MACHINERY PERFORMANCE MONITORING SYSTEM CONCEPT

by

William R. McWhirter, Jr., Roy D. Johnson, and John T. McLane

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PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT

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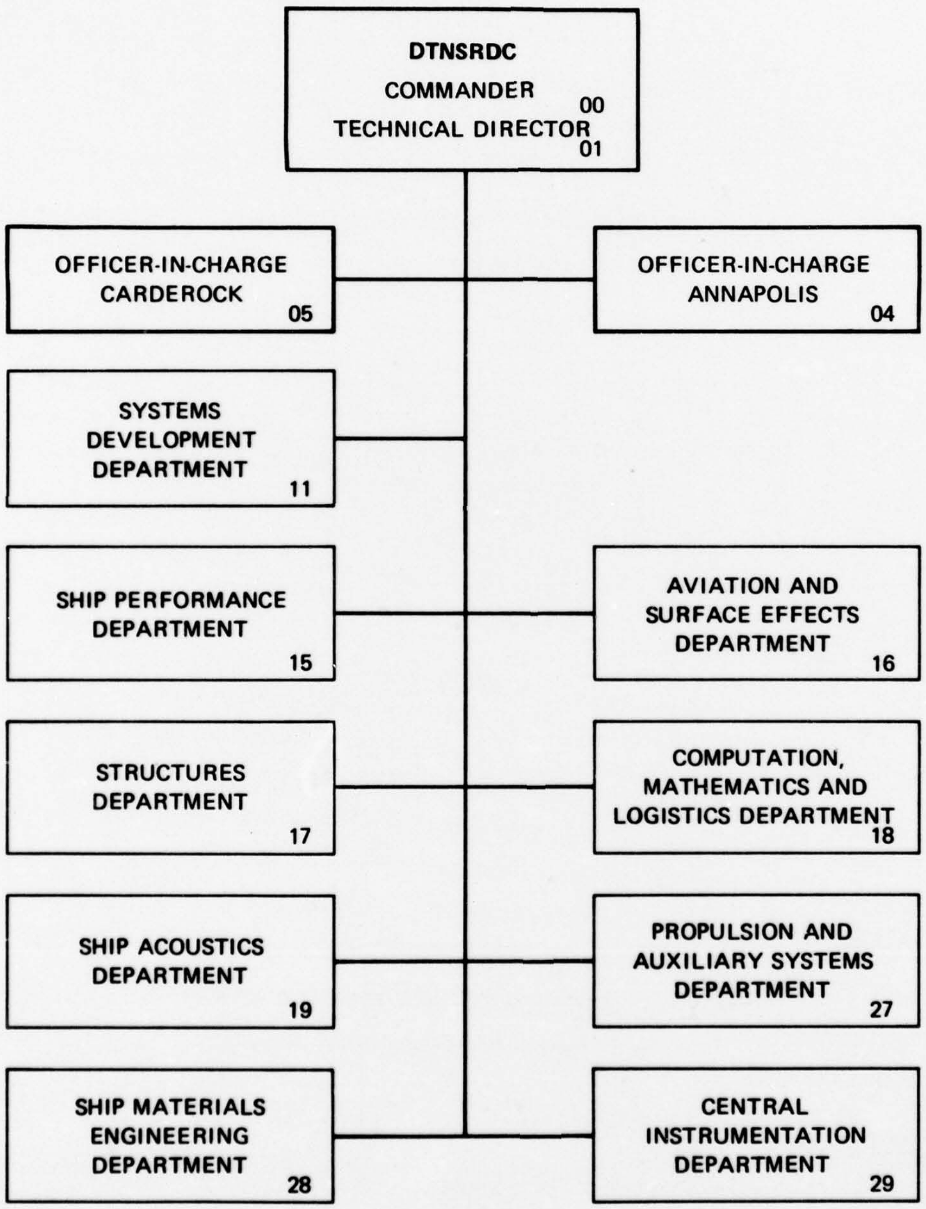

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There is an ever increasing emphasis on the need to improve ship operational readiness and effectiveness, while limiting manning requirements and reducing maintenance requirements and costs. The automation of propulsion and auxiliary machinery control and monitoring systems should be considered as one manner to achieve these goals. Operational availability of machinery is currently limited by maintenance procedures which rely

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largely on manual open-and-inspect procedures to determine machinery condition. This technique is generally not effective and, in view of recent engineered maintenance concepts, it is becoming inapplicable. A system is being developed that will enable shipboard personnel to predict maintenance action, to reduce maintenance time required, and provide a tool for maintenance management.

This report describes a concept for an instrumentation and monitoring system for naval shipboard machinery. Specific topics addressed in this report include:

(1) System capability requirements;

(2) Data collection;

(3) Local remote processing;

(4) Data transmission;

(5) Central data processing;

(6) Information display; and

(7) Supervisory system interface.

Consideration is given to the monitoring of the machinery control systems and the monitoring system itself in an effort to determine comprehensive machinery performance and potential.

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LIST OF ABBREVIATIONS

AC	Alternating current
A/D	Analog to digital (converter)
ALU	Arithmetic logic unit
AM	Area multiplexer
ASYNC	Asynchronous
ATE	Automatic test equipment
ATLAS	Abbreviated test language for all systems
Avg	Average
BIT	Built-in-test
BITE	Built-in test equipment
CAPMS	Condition and performance monitoring system
CDC	Control Data Corporation
CICWO	Combat information center watch officer
CMOS	Complementary metal-oxide semiconductor
CO	Commanding officer
CPU	Central processing unit
CRT	Cathode ray tube
CWO	Communications watch officer
DAS	Data Acquisition subsystem
DC	Direct current
DCA	Damage control assistant
DFT	Design for testability
DI	Data item
DOD	Department of Defense
DODD	Department of Defense document

External control word

Electronic Industries Association

Electromagnetic interference

Engineering officer of the watch

Frequency to digital (converter)

General purpose electronic test equipment

Hertz

Interactive application system

Institute of Electrical and Electronics Engineers, Inc.

Input/Output

Instruction register

Instrument Society of America

Kilo (thousand)

Light-emitting diode

Level of repair

Large-scale integration

Megahertz

Micropascals

Microseconds

Military Specification

Military Standard

Milliampere

Microprocessing unit

Medium-scale integration

Mean-time-between-failure

Mean-time-to-repair

MU	Maintenance unit
MUX	Multiplexer
NAC	Naval Avionics Center
NTDS	Navy tactical data system
OOD	Officer of the deck
ORMS	Operational readiness monitoring system
PCM	Pulse code modulated
PMS	Preventive maintenance system
PROM	Programmable read-only memory
RAM	Random access memory
RDT&E	Research, development, test and evaluation
ROM	Read-only memory
RMS	Root mean square
RMSE	Remote multiplexer - shared electronics
SAE	Society of Automotive Engineers
SDMS	Shipboard data multiplex system
sec	second
SEM	Standard electronic module
SER/PAR	Serial to parallel (converter)
SMPM	Shipboard machinery performance monitoring
SMPMS	Shipboard machinery performance monitoring system
TAO	Tactical action officer
Temp	Temperature
TC	Traffic controller
TRD	Test requirements document
V	Volt
XO	Executive officer

ABSTRACT

There is an ever increasing emphasis on the need to improve ship operational readiness and effectiveness, while limiting manning requirements and reducing maintenance requirements and costs. The automation of propulsion and auxiliary machinery control and monitoring systems should be considered as one manner to achieve these goals. Operational availability of machinery is currently limited by maintenance procedures which rely largely on manual open-and-inspect procedures to determine machinery condition. This technique is generally not effective and, in view of recent engineered maintenance concepts, it is becoming inapplicable. A system is being developed that will enable shipboard personnel to predict maintenance requirements, to reduce maintenance action, to reduce maintenance time required, and provide a tool for maintenance management.

This report describes a concept for an instrumentation and monitoring system for naval shipboard machinery. Specific topics addressed in this report include:

1. System capability requirements
2. Data collection
3. Local remote processing
4. Data transmission
5. Central data processing
6. Information display
7. Supervisory system interface

Consideration is given to the monitoring of the machinery control systems and the monitoring svstem itself in an effort to determine comprehensive machinery performance and potential.

ADMINISTRATIVE INFORMATION

This work was conducted in Fiscal Year 1978 under Work Unit 2730-100, Task Area SF 43 433 302, Program Element 62543N, and under Work Unit 2731-141, Task Area S0359.001, Program Element 63585N. The project was completed under the supervision of Mr. E. M. Petrisko; Head, Control and Simulation Branch, Automation, Control and Systems Effectiveness Division.

SL

INTRODUCTION

BACKGROUND

An underlying requirement for improved continuity of operation of shipboard machinery will be the ability to monitor the machinery systems. Monitoring is needed to provide continuous and immediate information on plant and component status, level of performance, and to detect equipment failures and predict impending failures so that corrective action can be taken by a supervisory control system. Concurrently, the information available on machinery components will reduce maintenance requirements by providing the capability for maintenance on-demand rather than on a regular calendar schedule.

The attainment of these goals is expected to embrace the technology of automated testing. Automatic test for machinery monitoring systems is a logical extension of state-of-the-art automatic test equipment for sophisticated electronics systems. ATE* techniques will be used to provide rapid detection, diagnosis, and prognosis for equipment fault identification and isolation.

The Navy's existing Planned Maintenance System for shipboard machinery can be improved. The system is time-consuming and sometimes it leads to unnecessary maintenance being performed. There is a lack of adequate reporting of machinery condition with little information feedback to determine causes of failure. In general, the existing maintenance practice is expensive and not as effective as it needs to be.

Machinery maintenance has become a costly burden. Required maintenance has been on the increase due to the size and complexity of ship's machinery. In general, open-and-inspect procedures are becoming less effective in view of recent engineered maintenance concepts. Also, the Navy's manpower costs are surging upward, while concurrently, the average skill level of enlisted personnel is declining.

Such conditions are leading the Navy toward the automation of ship functions. This includes the implementation of a limited manning policy

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*Definitions of abbreviations used are given on page v.

where the ship is controlled by a small supervisory crew. If the Navy is to employ a shipboard machinery performance monitoring system, then that system must be capable of providing:

1. Machinery operational status.
2. Machinery maintenance requirements.

Some expected benefits of machinery monitoring include reduction of forced outages, reduced operating costs, the ability to ascertain energy utilization and savings and to promote overall systems safety, reduced maintenance costs, maintenance performed on-condition, improved reporting reporting of machinery history, extended machinery life, and improved machinery systems operational readiness.

This report discusses a concept for an onboard machinery performance monitoring system for naval surface ships. The report will establish the guidelines, intentions, and direction for the development of this monitoring system capability. Specific topics included in the concept include:

1. System capability requirements.
2. Data collection.
3. Local remote processing.
4. Data transmission.
5. Central data processing.
6. Information display.
7. Supervisory system interface.

GENERAL SYSTEM DEVELOPMENT

The Chief of Naval Operations has established, via Advanced Development Program S0359-SL, certain requirements for successful implementation of an automated shipboard machinery performance monitoring system in the Fleet. SMPMS must offer the following capabilities:

1. Improve operational readiness through more accurate detection of degrading ship machinery performance.

2. Reduce logistic support costs through efficient detection and identification of faults at a lower level of repair.

3. Reduce the technical skill level and training required to maintain complex systems.

4. Reduce the time and manpower required to test complex systems.

5. Permit testing and fault analysis of systems beyond the practical capability of manual methods.

6. Provide improved operational performance due to reduced downtime of the machinery plant and auxiliaries.

If such an instrumentation system can achieve these capabilities and meet operational requirements, it should be an efficient automated diagnostic system that will gather reliable data to:

1. Ascertain machinery plant status.
2. Identify performance level.
3. Detect degrading system performance.
4. Predict impending system and component failures.
5. Detail the maintenance to be performed.

Definition

The SMPMS will be able to test and monitor the performance and physical condition of shipboard gas turbine, steam, or diesel main propulsion systems and their related auxiliary machinery systems. To accomplish this fully, the SMPMS must be able to provide and rapidly update information regarding:

1. Machinery plant status.
2. Machinery plant capability.
3. Diagnosis and indication of machine off-normal condition.
4. Detection of performance degradation (and rate of degradation).
5. Failure prediction.
6. Failure diagnosis.
7. Isolation of faults.
8. Anticipating maintenance requirements.
9. Scheduling maintenance.
10. Recording performed maintenance.
11. Maintaining machinery history.
12. Data recording for off-ship analysis.
13. Interface with any supervisory monitoring system for command such as an operational readiness monitoring system.

Approach

Systems integration for the SMPMS will be enhanced by the implementation of distributed intelligence network techniques. The utilization of microprocessors and microcomputer technology, and the delegating of local authority to satellite processors for supervision will strengthen monitoring system reliability and improve information throughput and quality by reducing signal traffic in the central terminal area. For this scheme to be properly implemented, there exists a requirement for a military standard for shipboard monitoring. A description of this requirement is located in Appendix A.

An indication of anticipated monitoring system information flow can be seen in Figure 1. This is not intended to be a system design; rather it explores the paths of machinery performance analysis information. Note the different levels of information and status display and that the characteristics/parameters of the machinery control systems are also monitored.

For a machinery performance monitoring system to be accepted and employed in a shipboard environment, it is mandatory that several vital capabilities be demonstrated. It should be:

1. Flexible - Capable of satisfying monitoring requirements for a number of machinery systems and equipments with a minimum change in its configuration.

2. Adaptable - Capable of performing critical functions by reallocation of tasks if part of the systems fail to function.

3. Reliable - Incorporating self-test, self-calibration, and a design which emphasizes conservative component selection.

4. Functional - Capable of safely performing the necessary processing tasks and storing the pertinent data for trend analysis (or other techniques) of machinery characteristics.

5. Operable - Easy for sailors to use with simple operating procedures and effective information output display requiring little or no technical interpretation.

6. Maintainable - Easy to maintain and repair, including self-diagnosis; consideration should be given to the Navy's standard electronic module program, which includes the "throw-away" maintenance concept.[1*]

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*A complete listing of references is given on page 63.

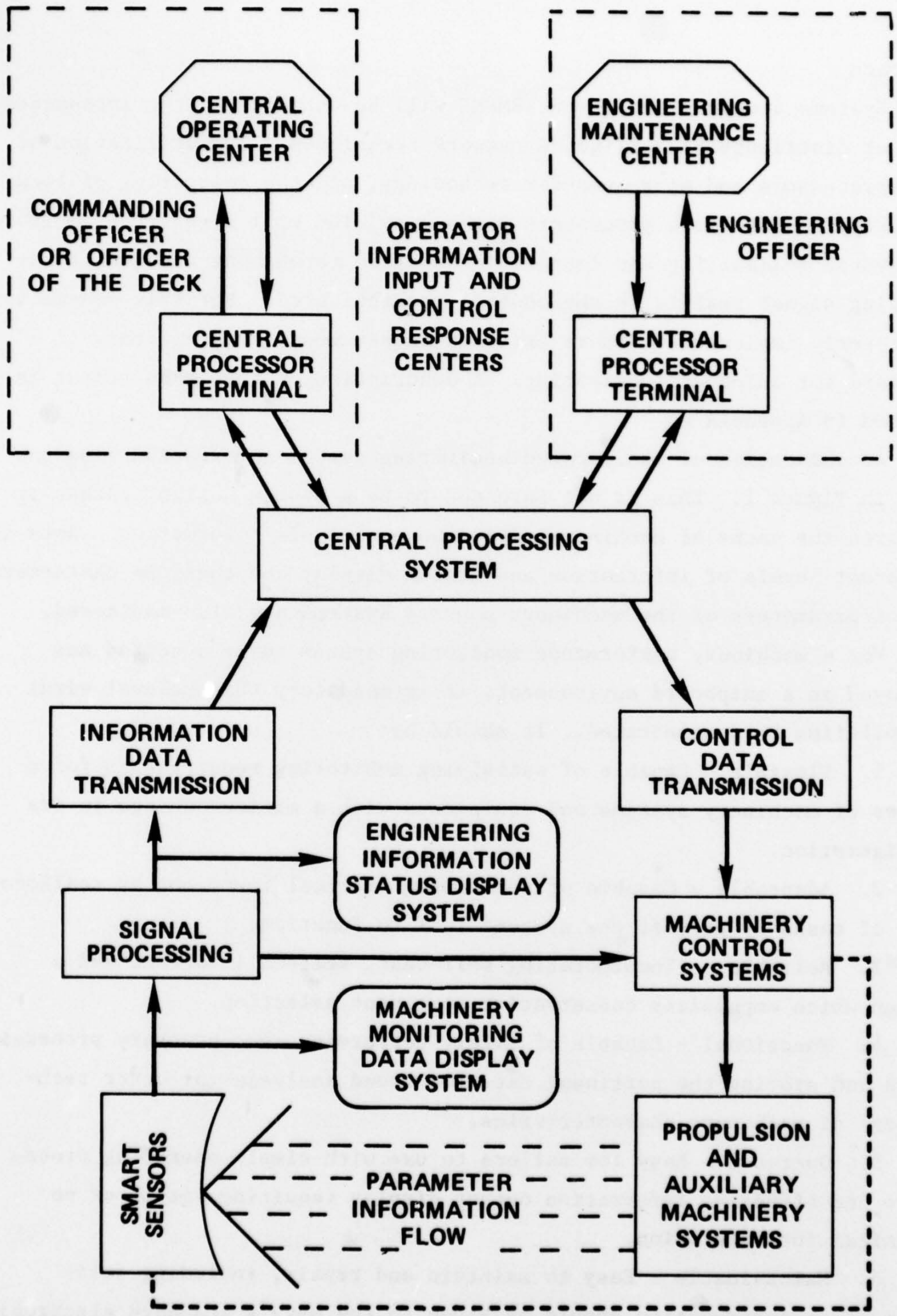

Figure 1 - Machinery Performance Analysis
System Information Flow Chart

The key elements of the monitoring system development are the:

1. System design, including processor and data storage requirements.
2. Human engineering and training requirements.
3. Hardware specifications.
4. Software standards.
5. Display standards.
6. System interface integration guidelines.

Integration of Programs

Technology is to be applied to this development program from other Navy system developments such as the shipboard data multiplex system and the gas turbine condition and performance monitoring system, the Naval Material Command program plan for automatic testing, standard shipboard minicomputer program, the Navy standard electronic module program and the operational readiness monitoring system development program. For more information on ORMS, see Appendix B.

The SMPMS advanced development program is unique because it emphasizes a rigorous analysis and testing phase of shipboard machinery to identify failure modes and assess the effectiveness of various failure detection and performance monitoring techniques.

MACHINERY SYSTEM TEST POINTS TO BE MONITORED

The selection of those machinery test points to be monitored is of tantamount importance if a SMPM system is to achieve its aforementioned goals. The machinery failure detection technology phase of the SMPMS advanced development program will have the responsibility for determining the test points. Questions such as - Who needs information? - What information is needed? - What are the information sources? - must be answered prior to the selection phase of this development program.

There are a number of difficulties encountered in the monitoring of nonelectronic equipment (as indicated by Dimmick in a previous report with restricted distribution):

1. Typically, electronic systems are compact and highly centralized. As a result, test-point density is quite high. In contrast, mechanical systems are quite decentralized both by their basic nature and by specific

design effort. Consequently, the test-point density is likely to be very low. This has significant implications in the adoption of an applicable philosophy for data acquisition and transmission techniques. The processing of sensed data may be more complex in some cases in that determination of whether or not a variable is correct may often require a computation involving several other dependent or independent variables rather than a simple comparison with predetermined limits.

2. The nature of failures in mechanical equipment is somewhat different from that in electronic equipment. Failure of mechanical equipment usually results in its complete inoperability and often in its destruction. As a result, automatic postfailure trouble diagnosis is of limited value.

3. Progressive failure in which failure of one equipment may cause failure of, or damage to, several others is a significant problem in mechanical systems. Fortunately, redundant equipments are usually provided for vital functions. From the standpoint of system operation and availability, sufficient warning of equipment failure to permit shifting the load to parallel equipment before the entire system fails is a far more urgent interest than a detailed analysis of why the system failed and what to do about it.

4. Most of the correct operating parameters in mechanical and electrical systems are heavily dependent upon system configuration and system loading. For this reason, no-load and off-line testing is of somewhat limited value.

5. Common practice in automatic test equipment is the application of a stimulus at a certain point and the evaluation of system response at another point. This is not a very useful technique in mechanical systems. Under some conditions, it may be possible to set up certain operating conditions for automatic analysis, but it is not realistic to assume that this can be done automatically by the test equipment.

6. Because of the heavy dependence on manual controls and troubleshooting, typical machinery installations contain a tremendous number of opportunities for failure, damage, or accelerated wear-out caused by operator inattention, inexperience, or ignorance. A prime concern in any automatic test system is its ability to detect and draw attention to improper or unsafe operating practices.

7. Typically, on-line automatic testing of electronic equipment isolates faults to the lowest level replaceable unit, usually, but not universally, to a replaceable printed circuit card. The card can be replaced to restore prime equipment operation and then discarded, repaired, or traded in at leisure. Corrective maintenance to restore prime mechanical equipment operation is rarely so simple. The lowest level replaceable unit is usually a mechanical part deep inside the equipment and, even if the difficulty is precisely known, the equipment must be taken out of service for an appreciable period while repairs are made.

As a follow-through on that previous work, the SMPM system will then gather information for use in the following areas:

1. Command information.
2. Ship or machinery plant control.
3. Machinery plant or component status.
4. Machinery plant or component efficiency.
5. Machinery plant or component failure detection/prediction.
6. Machinery plant or component maintenance requirements.

Specifically, the above information will be acquired from the LM2500 gas turbine condition and performance monitoring system, or a similar such propulsion machinery monitoring subsystem, and the auxiliary machinery systems. A preliminary listing of those required monitoring tasks, as required by ORMS and CAPMS for the FFG 7 class ship, are given in Appendixes C and D, respectively. Additional monitoring tasks in the area of auxiliary systems will be forthcoming from the advanced development program.

SYSTEM CONCEPT EFFECTIVENESS

At the beginning of the conceptual study, a choice between alternative system concepts is frequently necessary. In general, detail design data is not available at this time to properly evaluate the system design effectiveness in meeting the stated mission objectives. Consequently, the focus is on the effectiveness of the concept rather than the design.

The problem of evaluating system effectiveness early in the system life cycle has been addressed by the process known as System Concept Effectiveness Analysis.[2] The concept of effectiveness has been defined to include:

1. System Effectiveness - A measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a function of the system availability, dependability, and capability.

2. Availability - A measure of the system condition at the start of a mission. It is a function of the relationships among hardware, personnel, and procedures.

3. Dependability - A measure of the system condition at one or more points during the mission, given the sustem condition at the start of the mission.

4. Capability - A measure of the system ability to achieve the mission objectives, given the system condition during the mission. Capability specifically accounts for the performance spectrum of the system.

To be effective, a system must be ready to operate when called upon, it must operate over the time period for which the demand exists, and it must perform the required functions satisfactorily in the specified environment.

The system concept effectiveness analysis will be composed of two phases:

Phase I - Identification of the problem and the analysis criteria.

Phase II - Evaluation of alternate total system concepts.

Both phases of the analysis process are shown in Figure 2. By following a process which clearly defines the total problem and the analysis criteria, pertinent information and considerations can be developed for system concept selection. The process described in Figure 2 was used as a guide for this conceptual study.

SMPM SYSTEM DESIGN OVERVIEW

This section of the report presents some preliminary thoughts and requirements for the hardware implementation of the SMPM system. Some of the hardware systems are within state of the art; others are presently under development and appear feasible for inclusion in the conceptual design. Microprocessors are seen as good reliable units that should be used extensively in the design. In fact it is felt that the advent of microprocessors is the primary basis for cost-effective monitoring and fault diagnosis.

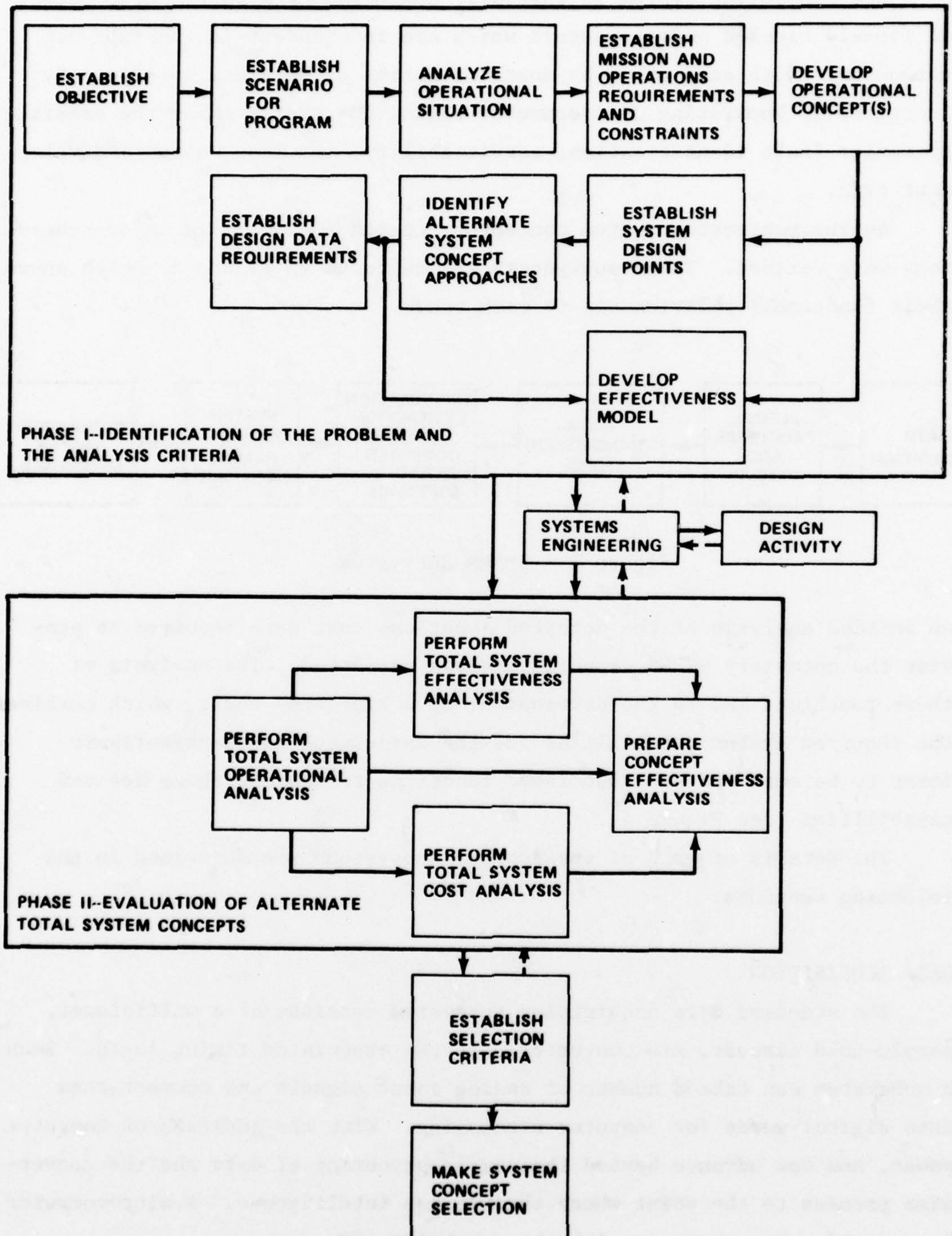

Figure 2 - System Concept Effectiveness Analysis Process

The monitoring system is initially conceived as a distributed network of loosely coupled microcomputers which are independent in function yet communicate with each other by means of serial or parallel bussing. By functionally separating microcomputer tasks, the system gains the benefits of easier fault identification, serviceability, and less software development time.

As the monitoring system conceptual design evolved, six major subsystems were derived. These subsystems are depicted in Figure 3, which shows their functional relationship to each other.

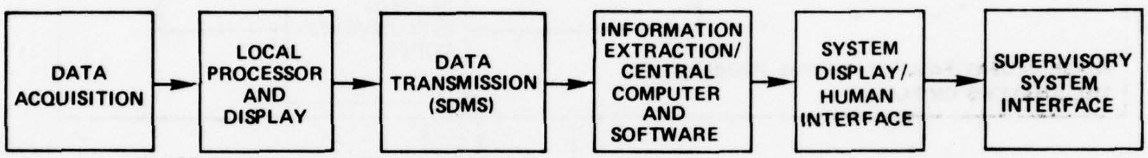

Figure 3 - SMPMS Subsystems

An initial analysis of the detailed functions that were required to provide the necessary SMPMS capabilities was performed. The analysis of these functions led to the development of a hierarchy chart, which outlines the required system capabilities and the associated hardware/software items to be employed and associated functions to achieve those desired capabilities (see Figure 4).

The details of each of these major subsystems are described in the following sections.

DATA ACQUISITION

The standard data acquisition subsystem consists of a multiplexer, sample-hold circuit, A/D converter, and the associated timing logic. Such a subsystem can take a number of analog input signals and convert them into digital words for computer processing. With the addition of computer power, one can advance beyond the simple gathering of data and the conversion process to the point where the DAS has intelligence. A microcomputer can provide the subsystem with the capability for:

1. Scaling, linearizing, calibrating, and converting sensed signals to engineering units.

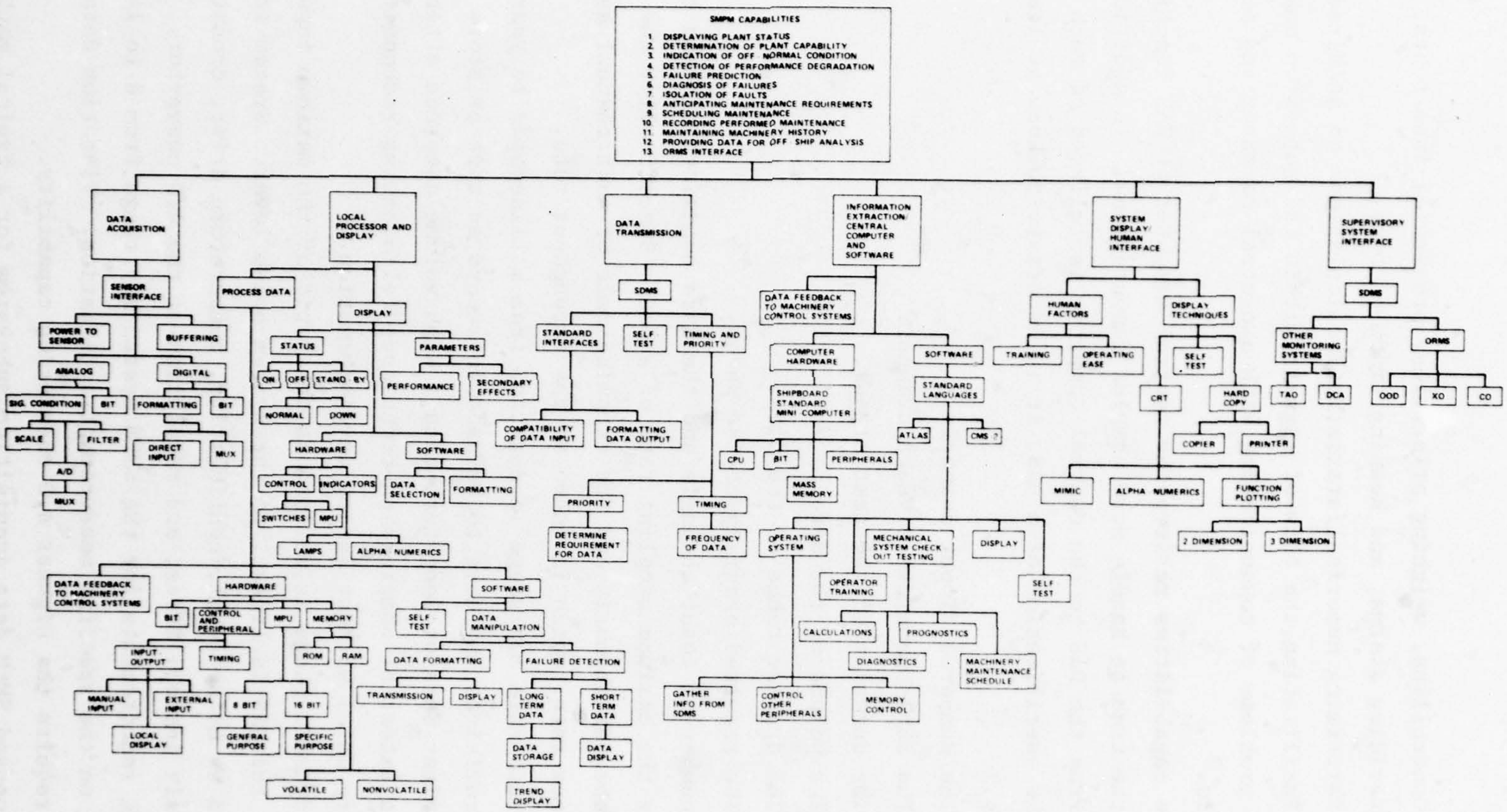

Figure 4 - SMPMS Capabilities and Function Chart

2. Controlling, weighing priorities, processing interrupts, comparing limits, providing alarms, and keeping track of time.

3. Performing numerical/statistical calculations on acquired data.

4. Facilitating the flow of signals within the subsystem and simplifying the problems of communicating with a central computer and other peripherals.[3]

These capabilities relieve the central computer of DAS functions and allow it the time to handle more complex computations. In addition, the data bus from the DAS to the central computer is relieved of much traffic.

In the specification of a DAS, it is necessary to know at least six parameters.[4]

1. The number of input channels.
2. The data bandwidth of each channel.
3. The duration of the test signal.
4. The volume of the data.
5. The dynamic range of the data.
6. The required accuracy of the data.

The number of input channels and the data bandwidth of each channel determines the maximum sampling rate of a DAS. Specifically, the product of the number of channels and the sampling rate of each channel expresses this maximum rate, which is known as the throughput rate.

The test data may range in duration from milliseconds to years. Special provisions may have to be made to record on tape or store short-term transient data or long-term data. High volume data can often be reduced in extent by compression techniques (eliminating redundant or unnecessary data) without losing any information.

The dynamic range is defined as the ratio of the maximum input signal, for which the DAS is linear, to the system noise level. System accuracy is determined by noise level, nonlinearity, temperature drift, crosstalk, power supply instabilities, and resolution of the A/D converter. A/D resolution requirements for the SMPM system may range from 8 to 14 bits depending on the specific measurement application. Vibration data will probably require the highest A/D resolution capability.

A proposed SMPM data acquisition subsystem for a typical machinery space is shown in Figure 5, as outlined by dashes.

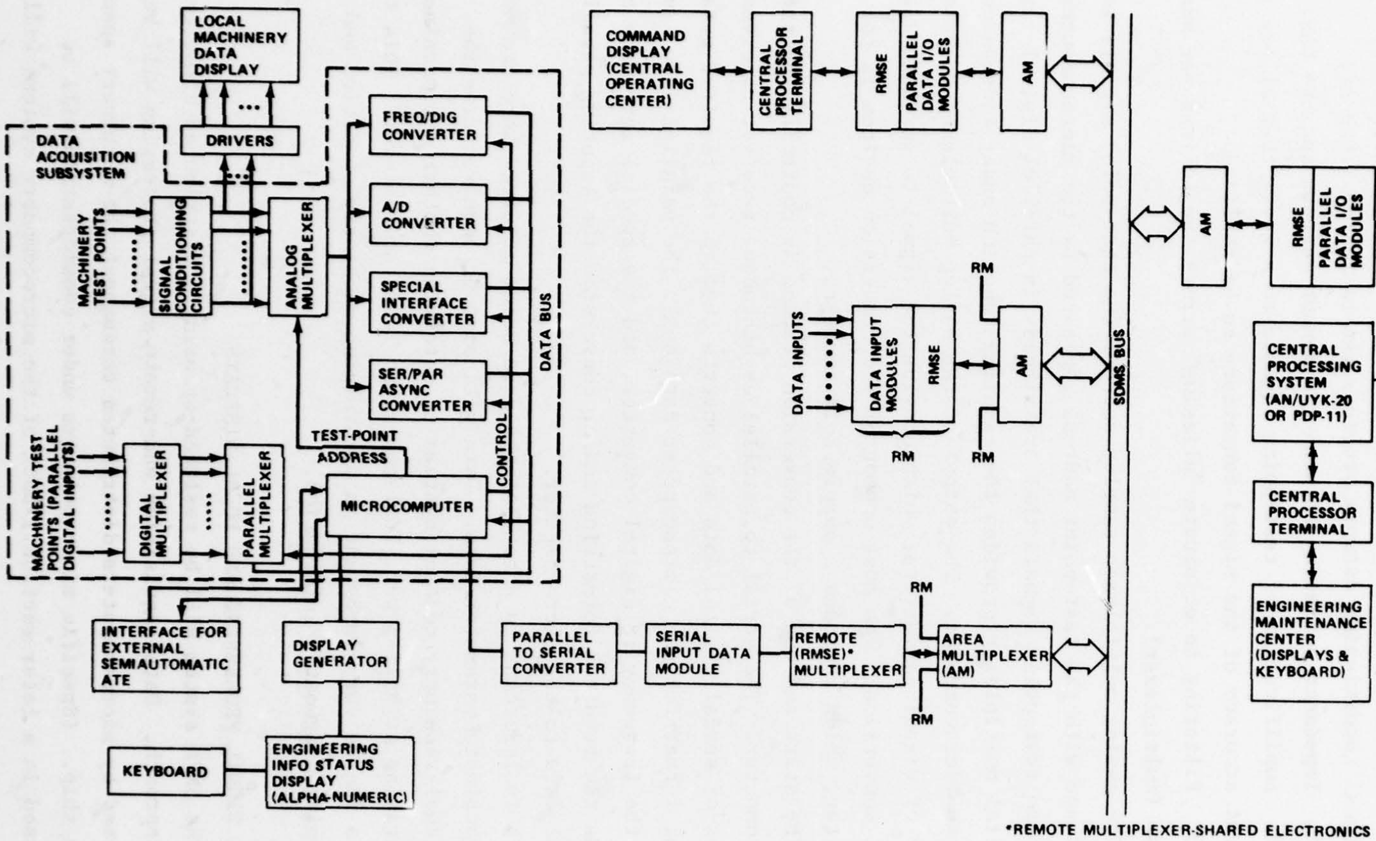

Figure 5 - Shipboard Machinery Performance Monitoring System Concept

Provision is made for accepting both analog and digital input signals. The signal conditioning network provides the basic functions of:

1. Impedance buffering between the sensor outputs and the DAS.

2. Amplification of test-point signals to a level that allows the inherent accuracy of the signal converters to be realized.

3. Filtering to eliminate "aliasing" errors due to improper sampling process (multiplexer).

The analog multiplexer samples each of the test-point signals in accordance with the test-point address generated by the microcomputer. For those test-point signals that are already in parallel digital format, a digital multiplexer provides the sampling function under address control from the microcomputer. The output of the analog multiplexer feeds a number of signal converters, which provide the signal to parallel digital format conversion. The most common of the conversion devices is the A/D converter, which includes a sample/hold circuit.

The start and end of the conversion process is controlled by the microcomputer. The serial to parallel asynchronous receiver receives samples of serial digital data and converts them to the required parallel digital format for the microcomputer data bus. The parallel input interface, the frequency to digital converter, and the special interface also provide the required formatting and/or conversion for inputing parallel digital data to the microcomputer.

It is important to note that the data being acquired here are not only machinery parameter data. Data will also be acquired from the individual machinery control systems to determine whether the machine is operating at half-power, full power, no load, or whatever. This type of data can be very important in determining machinery condition and developing diagnostic information.

REMOTE SIGNAL PROCESSING AND LOCAL DISPLAYS

The SMPM system will be realized by using a distributed computer network approach. Data acquisition and remote signal processing will be performed by microcomputers distributed throughout the machinery spaces in the ship. (Specific microcomputers under consideration will be discussed in a later section.) Each of the microcomputer systems will

have access to a larger central computer via the SDMS as was shown in Figure 5. The computer network offers the following advantages:

1. Much of the signal processing effort can be performed by the remote microcomputer, thus relieving the central computer of considerable computational work.

2. Processing at the microcomputer level also relieves the network bus of much data and network protocol traffic.

3. The modular design inherent in a distributed system enhances failure tolerance and permits graceful degradation in the event of failures.

The lowest level monitoring system is the machinery monitoring data display system which uses MSI or LSI logic to perform relatively simple operations on the analog signals at the outputs of the signal conditioning circuits (see left portion of Figure 5). A typical operation would be to compare amplitude data with predetermined limits to decide which parameters are in the desired operating range. When a parameter drifts outside the desired range, a comparator output would drive a light-emitting diode to indicate the status. A possible display philosophy is to have warning and fault indicators; these would be LED devices respectively colored amber and red. The amber light would indicate that the parameter is outside the desired operating range and requires possible attention though the machinery is still functionally operating. A red light would alert personnel to a fault that needs immediate attention. In some instances, a parameter may temporarily drift outside its range. By interposing a latch circuit between the comparator and the LED, the temporary excursion can be "latched" and retained as a warning or fault status until the latch is reset by the attending personnel. This would be of particular value in identifying intermittent problems.

The above monitoring/display system has the advantages of simplicity, long-life, and being electrically close to the sensed data. In the event of a component failure (multiplexer, multiprocessor, etc) in the data acquisition system, fault data would still be available.

As shown in Figure 5 the microcomputer controls the data acquisition system, processes data, and supplies commands and data to the information status display and SDMS bus. The power and speed of the microcomputer will depend on such factors as:

1. The number of test points to be multiplexed.

2. The extent and complexity of the computations performed by the microcomputer.

3. The response time required of the microcomputer.

4. The control and data load presented by the information status display and SDMS channel.

High performance requirements may require the consideration of two microcomputers with one dedicated to control functions and the other committed to computations. Considerations should also be given to the evolution (nonexistent yet) of high-end microcomputers which were defined by the 1978 International Solid-State Circuits Conference[5] to have the following capabilities:

1. Perform greater than a half-million instructions per second.

2. Have an address space greater than a megabyte.

3. Contain wide data paths on the chip (typically 16 bits wide).

4. Handle a wide variety of data types with a very flexible instruction set.

All microprocessor-based systems within SMPM will incorporate a continuous self-test (or BIT) feature; primarily through the use of software. The software set will utilize some portion of memory (ROM) to test the basic instruction set, internal data paths, memory, and other components. Hopefully, the addition of BIT circuitry to the computer systems will be minimal if not zero.

The engineering information status display will service the equipment in a given machinery area. Machinery data can be accessed by means of a limited keyboard and displayed as alpha-numeric information expressed in engineering units. The capability to access processed data such as averages, etc, will be available. The display generator accepts data from the main memory of the microcomputer and processes it for display on the graphics-output device such as a cathode ray tube display. The main function of the display generator is to refresh the display device by storing data in buffer registers and to periodically scan these data for presentation on the raster screen. Other types of displays such as LED screens and gas plasma displays are under consideration. For any of the

various types of display systems, additional intelligence and flexibility can be realized by using a microprocessor-based display generator.

A strong candidate for future display systems is the AN/UYQ-21, which is being developed as a standard shipboard digital display for the 1980-1995 time period. To satisfy the requirements for different users and applications, the AN/UYQ-21 is based on a modular design with attendant increase in reliability, maintainability, and supportability.

The AN/UYQ-21 display system provides various configurations of consoles, large screen displays, automated status boards, remote communication stations, remote data readouts, remote keysets, and other related equipment to allow integrated operation of the display in a shipboard environment. The UYQ-21 will provide both sensor data display (acoustic, radar, etc) and computer data display (graphics, conics, alpha-numerics, etc). Improvements of the UYQ-21 over the AN/UYA-4 (the present Fleet display standard) are:[6]

1. Remote alpha-numeric CRT displays.
2. Automated status boards.
3. Advanced large screen displays.
4. Recording of sensor and computer data.
5. Detection enhancement using time-compressed delays.
6. Scan converted video to replace special purpose displays.
7. New flexible word formats.
8. Real-time, program controlled source switching.
9. Liquid conduction cooling.
10. State-of-the-art technology.
11. High-speed rasters for display of acoustic/vibration data.
12. Higher data rates.
13. Enlarged software controlled symbol repertoire.
14. Expanded (and secure) communications.
15. Reduced cabling through use of serial data transmission.
16. Increased modularity.

DATA TRANSMISSION VIA SHIPBOARD DATA MULTIPLEX SYSTEM

At present all shipboard electrical wiring is realized by point-to-point dedicated cabling. The greatest problem inherent in this conventional

wiring scheme is the interdependence of ship subsystems on the cabling system. Any modification in a subsystem's interface or location will affect other compartment wiring. To avoid the cost and delay of such modifications and to gain other certain advantages, the SDMS system is being designed for use in future ships.

Some of the well known advantages of SDMS are found in increased flexibility, reliability, survivability, transmission accuracy, and weight and space conservation. In effect, SDMS will decouple ship subsystems by using standard SDMS interfaces and standard multiplex cabling throughout the ship. New or modified subsystems can then interface with standard modules without affecting any other subsystem wiring.

The following brief discussion of the SDMS operation is based upon Figure 6, which outlines the functions of the SDMS. Signal inputs from the various data sources are first interfaced to the SDMS system through input/output modules that convert different signal types into a standard digital format for SDMS transmission.

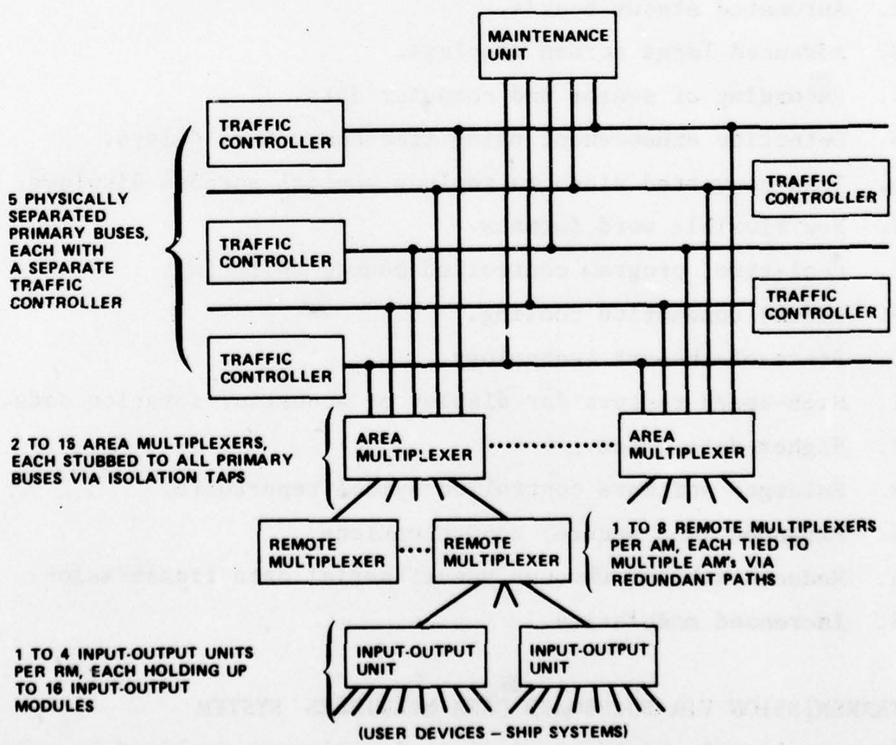

Figure 6 - Shipboard Data Multiplex System

Each remote multiplexer has the capacity for holding 64 I/O modules and would normally be located in s ship department containing a significant number of test signals. The RM also multiplexes the outputs of all the I/O modules and forwards the time-division-multiplexed data to the area multiplexer, which serves a number of RM's in a given area. The AM multiplexes the data at its input terminals and translates the composite signal into a frequency-division-multiplexed signal on one of four data channels in the 40 to 80 MHz range. The fifth channel is reserved for control messages from a traffic controller, which is associated with each of the five primary buses. Each TC monitors the four data channels on its particular bus and offers idle channels to the AM's for data transmission. One maintenance unit is provided for the entire SDMS system. The MU provides performance monitoring, fault detection and diagnosis, and system connection listing.[7]

The operation of SDMS is asynchronous, with the system intelligence distributed throughout the network in the RM's. Each RM contains a clock and a programmable read-only memory which contains all the information necessary to control message transfers between RM's. An RM can send or request a message from another RM at any time. Part of the inherent survivability of SDMS is seen in the multiple transmission paths that are randomly selected for each message. There are two possible paths through each RM; four possible paths between the RM and AM; and 20 possible paths from AM to AM. A more detailed discussion of the SDMS operation can be found in "Inside SDMS: A Technical Look."[8]

From the designer's point of view it is essential that new subsystems which require shipboard information transfer be compatible with the SDMS. At the present time, the interface function between the subsystems and the SDMS is being performed by the SDMS I/O modules. A list of available modules for some of the common signal types is shown in Table 1. These various I/O modules provide the capabilities for interfacing different data sources. If data rate requirements can be satisfied, the most efficient utilization of the SDMS system is realized by using the serial input modules as shown in Figure 6.

TABLE 1 - INPUT/OUTPUT MODULES FOR SDMS

1 - DC ANALOG INPUT MODULE - Converts four independent channels of balanced or unbalanced DC analog signals to 12-bit binary pulse code modulated data. Each channel is separately buffered to provide an input impedance greater than 1 megohm. The dynamic range of the input signal is +10 to -10 v. Data staleness due to sampling, 4-to-1 multiplexing and conversion is less than 300 microseconds.

2 - AC ANALOG INPUT MODULE - Converts two independent channels of balanced or unbalanced AC analog signals (either 60 or 400 Hz) to 12-bit binary PCM data. The channel input impedance is greater than 1 megohm. Strapping options provide for a maximum input range of 20 v. peak-to-peak, 26 v. rms or 115 v. rms with independent strap option for each channel.

3 - SYNCHRO INPUT MODULE - Converts two independent channels of 90 v. rms synchro inputs to 15-bit binary angle PCM data. A strapping option provides for use of the module in 60 or 400 Hz synchro applications. Separate AC references are accepted for each channel. The input impedance is 10,000 ohms line-to-line with 100,000 ohms isolation line-to-ground.

4 - DISCRETE INPUT MODULE (ISOLATED) - Converts 32 discrete input channels into dual 16-bit PCM data words. The module accepts positive or negative DC, bipolar, or AC voltages. Of the 32 input channels, 24 accept input signals in the range of 3-75 v. rms and eight cover the range of 75-140 v. rms. Solid-state optical couplers provide a high level of signal isolation. Four input channels (selected by strap option) can be designated to be aperiodic inputs which are continuously monitored off-line and transferred through SDMS only when the input state changes. All channels provide 1500 v-μsec of transient suppression.

5 - DISCRETE INPUT MODULE (SWITCH CLOSURE) - Is identical to the above module except that the user equipment need only provide switch contacts. A switch closure (resistance less than 10 ohms) is interpreted as a logical ONE and an open circuit (resistance greater than 1 megohm) is a logical ZERO. The current flow through the user equipment is less than 1 mA.

6 - SERIAL DATA INPUT MODULE - Accepts four channels of serial data (any two of which can be active simultaneously at input rates of 75, 150, 300, 600, 1200, 2400, 4800 bits per second). Each channel can interface with EIA RS-232-C* or MIL-STD-188C.

7 - PARALLEL DATA INPUT MODULE - Provides a MIL-STD-1397, Type B (NTDS FAST) interface for a 32-bit parallel transfer of data in the computer-to-SDMS direction. The interface includes external function request and acknowledge plus output data request and acknowledge control lines. The continuous transmission rate is 27,272 32-bit words per second.

8 - DC ANALOG OUTPUT MODULE - Drives four independent analog output channels with +10 to -10 v. DC derived from a 12-bit PCM data input. The module outputs are short-circuit-proof and will drive a 10-mA load on each channel.

9 - AC ANALOG OUTPUT MODULE - Drives two independent 400-Hz output channels that are scaled to a common 115 v., 400-Hz reference source. Each output channel is derived from a separate 12-bit multiplying digital-to-analog converter and provides a full-scale output of 20 v. peak-to-peak. The outputs are short-circuit-proof and can each drive a 10-mA rms load.

10 - SYNCHRO OUTPUT MODULE - Converts a 12-bit binary angle to a three-wire, 90 v. synchro output. The module will accept either a 60- or a 400-Hz synchro reference signal. The output is short-circuit-proof and will drive a 100-mA load.

11 - DISCRETE/SERIAL OUTPUT MODULE (LOW LEVEL) - Drive 32 output channels with discrete data or (via strap option) serial data at 75, 150, 300. 600, 1200, 2400, or 4800 bits per second. The interface is compatible with MIL-STD 188C standard low-level or EIA RS-232-C.

12 - DISCRETE OUTPUT MODULE (ISOLATED) - Provides 16 solid-state relay outputs that will switch user-supplied AC or DC voltages in the range of 3-140 v. and 10-1000 mA. The outputs can be used for discrete signals or serial data at rates up to 150 bits per second.

13 - PARALLEL DATA OUTPUT MODULE - Provides a MIL-STD 1397, Type B (NTDS FAST) interface for 32-bit parallel transfer of data in the SDMS to computer direction. The module can operate in either the interrupt mode or the request/acknowledge mode.

*The serial input/output interface standard specified by MIL-STD-188C is the military version of the electronic industry standard EIA RS-232-C.

However, an important disadvantage of the serial input modules is that individual serial channels cannot be externally addressed from another location. To have this external addressing capability, one of the SDMS parallel data input modules would have to be employed.

CENTRAL COMPUTER FOR THE MONITORING SYSTEM

The central computer for the SMPMS serves as the main processing unit for the monitoring system and it would probably be located in the Engineering Maintenance Center. The various data acquisition subsystems transmit data via SDMS to the central computer for higher level processing, as was shown in Figure 5. Some of the major functions of the central processing system are:

1. Gathering information from the SDMS bus and storing it in memory.
2. Provide graphical commands and data to the display generator.
3. Request or send messages to the various user subsystems such as the Central Operating Center and Data Acquisition Subsystems.
4. Perform high level calculations, fault diagnosis, trending.
5. Provide software for self-test capability.
6. Provide software for operator training.

A task to select the central computer for the SMPMS will be a major effort for the initial monitoring system design.

The Defense Department, according to draft DOD Directive 5000.xx, has proposed to limit military computers for major weapons systems to six standard architectures. These computer architectures will be selected from among those most commonly used. Candidate computer systems for this selection are Sperry Univac's AN/UYK-7 and AN/UYK-20 for the Navy; Rolm's AN/UYK-19 for the Army and Navy; Litton's AN/BYK-12 for the Army; Westinghouse's AN/AYK-15 Dais system for the Air Force; Bunker Ramo's AN/GYQ-21 for many agencies; CDC's AN/AYK-14, CDC's 484, and Digital Equipment's PDP-11.

At the present time the most likely choice for use as the SMPMS central computer is the AN/UYK-20(V),[9] which is a military standard, general purpose machine for small and medium-sized applications. The AN/UYK-20 is attactive to the military because of its high reliability, modularity, versatility, and serviceability. Fast computation capability and adapt-

ability are provided by a memory with a 750 nanosecond read-write cycle and a microprogrammable control section.

The AN/UYK-20 is well suited to real-time applications such as weapons control, display controlling or data systems. A multilevel interrupt capability is hardware-initiated thus providing a fast setup procedure prior to the actual interrupt. The hardware eliminates much of the interrupt processing routines which require longer execution times. Shorter processing times are also realized by the frequent use of general purpose registers for quick storage and manipulation of real-time data.

The AN/UYK-20 construction is modular in accordance with MIL-E-16400. The central processor/input-output controller, memory, power supply, maintenance panel and operator panel are the basic modules. The electronics reside on printed circuit boards designed with medium-scale integration devices. The functionl electronics architecture of the AN/UYK-20 is shown in Figure 7.

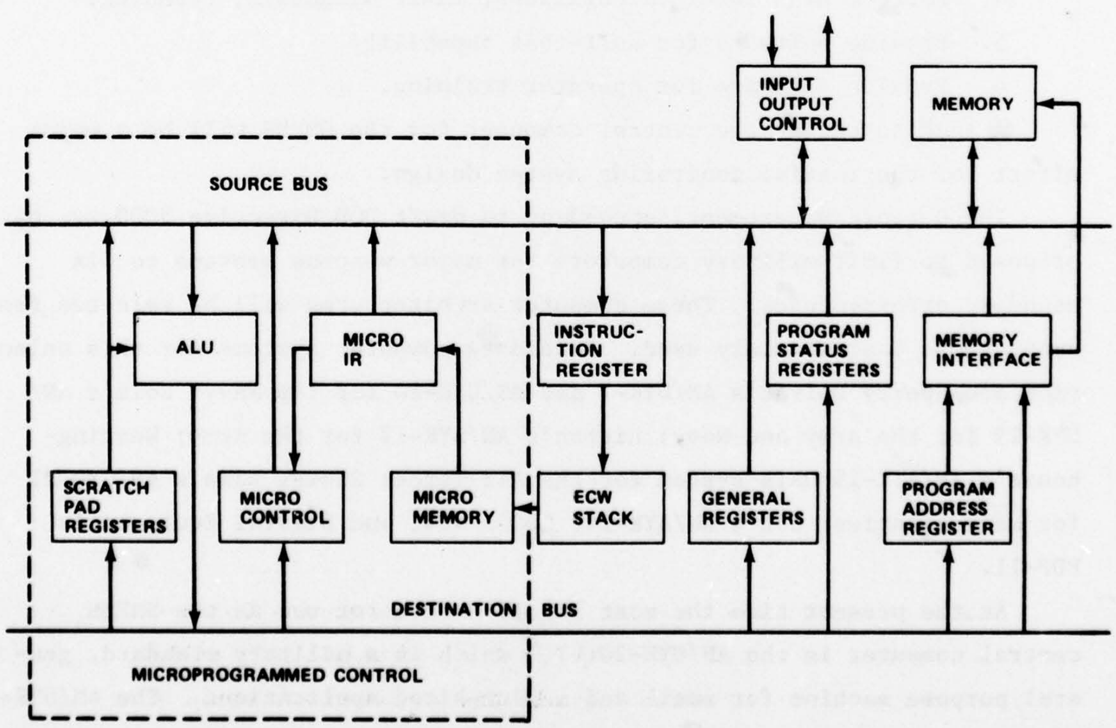

Figure 7 - Functional Architecture of AN/UYK-20

Optional design features may be realized by simply inserting plug-in modules. With full accessories, the AN/UYK-20 provides:

1. 65,536 (65K) word memory.

2. 192 word nondestructive read-only memory.

3. 16 input/output channels consisting of any combination of parallel channels in groups of four and serial channels in groups of two.

4. Direct memory access.

5. 32 general registers.

6. Real-time clock and monitor clock.

7. 512 words of user defined micromemory.

Each of the printed circuit cards are easily accessible for maintenance. Access to the maintenance panel and test points is attained by opening the cabinet front. Fault diagnostic routines are available as resident programs in the read-only micromemory and also as more comprehensive external programs which can be loaded into memory.

The input/output controller communicates with external devices by means of the IOC peripheral equipment interface. Parallel or serial interfaces are available as required. The IOC peripheral equipment parallel interface has a maximum of 4 groups of 4 input/4 output, 16-bit channels. Data transfer can be made using 8-, 16-, or 32-bit word-parallel interfaces. The 32-bit word transfer would use two 16-bit channels in a dual channel mode. Serial interfaces can be provided in 2-channel groups, with the IOC providing the serial to parallel and parallel-to-serial conversion. Control signals and interface lines meet the specifications of EIA Standard RS-232C, MIL-STD-188C, or NTDS (serial). A summary of the maximum I/O transfer rates according to channel groups is shown in Table 2.

A possible, future candidate for the SMPMS central computer is the Norden PDP-11/70M fully militarized microcomputer. One of the important advantages of the PDP-11/70M is that it uses the same extensive and proven software as does the commercial Digital Equipment Corporation PDP-11/70. The PDP-11/70M can utilize important interfaces such as Military Standard 1553A and the Navy Tactical Data System. Being modular in construction, the PDP-11/70M provides quick and easy replacement of such components as the CPU, power supply, core memory, and I/O hardware.

TABLE 2 - MAXIMUM I/O TRANSFER RATES FOR AN/UYK-20

Parallel Channels (Thousand Words per Second)					
Interface and Voltage (Type)		No. of Channels Active			
		1-4	5-8	9-12	13-16
-15 V. (NTDS)	IN	41.6	83.3	124.9	166.6
	OUT	41.6	83.3	124.9	166.6
+3.5 (A NEW) and -3.0 (NTDS)	IN	190.0	400.0	750.0	1000.0
	OUT	190.0	400.0	750.0	1000.0
NTDS Serial Channel			150,000 32-Bit Words/Sec		
EIA-STD-RS 232C and MIL-STD-188C Serial - (Bits per Second)					
Asynchronous Channel		2400, 1200, 600, 300, 150, or 75			
Synchronous Channels		to 9600			

The PDP-11/70M[10] features a 2-million word memory reach with high-speed mass storage controllers and a high-speed floating point processor. The complete PDP-11 instruction set of over 400 instructions is available to the user. Other features of interest are 32-bit internal data paths, multiple priority level vectored interrupts, highly developed diagnostics, and extensive parity checking for realiability.

MONITORING SYSTEM SOFTWARE

All monitoring system software will utilize a standard DOD software set. Off-line testing of electronic or nonelectronic subsystems must use ATLAS software which was recently adopted by the Defense Department as part of DOD-1. ATLAS is presently the IEEE standard automated test equipment language for all systems. The SMPMS central computer will use CMS-2 (a subset of DOD-1 and similar to Fortran IV) as its real-time processing language for monitoring and computations.

The monitoring system software can be grouped into the following packages:

1. Machinery monitoring software package

a. Data base management of the machinery histories and the scheduling of machinery maintenance.

b. Condition trending which would include both disgnostics and prognostic routines.

c. Calculations to determine efficiencies, project expendables (fuel, water, etc).

2. Operational software (I/O software)

a. Gather information from the SDMS bus.

b. Control memory access for input and retrieval of data.

c. Control flow of data to the peripherals (including data flow to ORMS).

3. Display packages

a. Format two- and three-dimensional engineering charts.

b. Format mimic software.

c. Capability to list program.

d. Input data to monitoring system from keyboard.

e. Implement fiber optic pen for altering displays.

f. Interactive graphic display (operator can alter display).

g. Software packages for non-CRT displays (if such displays are used).

Self-Test and Self-Diagnosis

Software routines (resident and mass storage) will be provided to test and diagnose faults in the monitoring system hardware and software. The resident self-test routines should operate continuously by utilizing some portion of the provessing time. Mass storage routines may be called for more detailed diagnostics. The actual circuit level to which the diagnosis is performed will be determined after an appropriate level of repair analysis.

Operator Training

The specific requirements for an effective personnel and training plan will be determined during the advanced development phase of this project. It is intended that the plan will address:

1. A definition of realistic training requirements.
2. The development of valid performance criteria and measures.
3. The development of effective training procedures.

It is planned that the cost and efficiency of training can be optimized by integrating some training capability into the design of the SMPMS. This would take the form of software routines which would be especially prepared to simulate faults and equipment degradations. Using these routines, the operators could receive a certain amount of on-the-job training by being guided through typical malfunctions as a result of the operator's interaction with the system controls/displays.

This onboard concept of training will receive careful scrutiny and analysis during the system design process. Particular attention, as regards operators, will be given not only to the human engineering of controls/displays but also to the functional analysis, mission descriptions and reviews of similar systems. This integrative type of approach is planned to ensure a "user-friendly" system and also to provide useful data for personnel and training specialists.

Constraints on Software Development

Those documents impacting initial monitoring system software development include:

1. Weapon Specification WS8506, Revision I - Digital Computer Program Documentation (1 November 1971).

2. Secretary of Navy Instruction 3560.1 - Tactical Digital Systems Documentation Standards (8 August 1975).

3. Military Specification S-52779 - Software Quality Assurance Program Requirements (5 April 1974).

The Department of Defense has created both a software management steering committee and a directive (DODD 5000.29) for managing computer programs. The directive establishes policy for the management and control of computer resources during the development, acquisition, deployment, and

support of major defense systems. Two important but often neglected stages in the life-cycle of a computer program are the checkout and certification phases. These phases establish the process of proving that the delivered program meets the requirements established for it. To achieve this end all shipboard monitoring software should be tested and proven according to Gallant's recommendation.[11]

All of these documents, policies, and committee findings will be used in developing the SMPM system software.

Displays and Human Interface

In designing the Engineering Maintenance Center for the SMPMS, human factors engineering principles, techniques, and criteria will be applied to:

1. Properly assign systems functions to personnel or equipment, with emphasis on elimination of nonessential human assignments through increased equipment capabilities.

2. Ensure the equipment and displays are designed to optimize personnel performance in carrying out routine and critical tasks in the minimum time with minimum errors.

3. Clearly define procedures and steps that the operators must take for any operational contingency.

4. Provide information and data useful to personnel and training specialists in preparing training plane and documents.

The point at which human factors engineering consideration will have the greatest impact on effective personnel utilization will be during the "function allocation" of the system design. Therefore, system designers will perform the human factors engineering necessary to determine the effective assignment of functions between men and machines, based upon the capabilities and limitations of each. The things that a machine does best (sense, display, correlate, filter, process) will be given to the machine and those that a man does best (operate, select alternatives, compare, exercise judgment, modify plans/procedures to meet new situations) will be assigned to men. In addition, a deliberate effort will be made to assign to machines those functions which man may be able to perform well under some conditions, but which tend to overload the operator and/or

increase personnel requirements under other conditions. All of this will be subject, of course, to tradeoffs with feasibility and the cost of implementing the functional assignments.

It is planned that the Engineering Maintenance Center contain information display consoles to be used by operators in the monitoring and maintenance of ships propulsion, axuiliary, and electrical systems. Details of that workspace, including the manning, arrangement, and configuration of consoles and ambient lighting, will be determine during the validation/advanced development phase of this project. At that time, the detailed operations of those systems will be analyzed and allocation of functions to operators will be determine. This functional allocation, along with the analyses of system operational procedures, will provide the basis for the detailed arrangement and configuration of the display consoles. This same allocation, along with the man-machine analysis of the consoles and their displays, will also be the basis for personnel and training requirements and plans.

After initial analyses, the conoles and their displays will be presented in mock-ups to demonstrate not only the Engineering Maintenance Center capability, but also to show user workloads and to identify any parameters which may affect user performance and acceptance/friendliness.

During the validation/advanced development phase, human factors engineering analyses of the Maintenance Center will address such initial requirements and considerations as follows:

1. The impact, if any, of the location of the Center aboard ship.

2. The details of operator control/display hardware for examining detailed test-point information on the systems equipment, data trends of machinery history plots, and system fault isolation.

3. The appropriate use of color displays, mimic displays, cathode ray tube displays, transilluminated displays and light emitting diodes.

4. Arrangement of displays/controls by frequency of use, by similarity grouping, by priority location, proper angle for viewing and for minimum parallax and glare.

5. The sequential display of all monitored data with options for interrupting the sequence at any time to examine data test points while not affecting the monitoring sequence.

6. The use of appropriate fault and alarm indicators which periodically reactivate until corrective action is taken.

Demonstrations and tests will be conducted to ensure that the operational requirements defined by the Chief of Naval Operations have been translated into test objectives. The demonstrations will:

1. Show how well the operators have been integrated with the system elements and operational requirements.

2. Define man/machine interfaces and areas critical to system mission.

3. Address man/machine tradeoffs and their impact.

4. Address demands on operator performance to determine if overload situations can occur which might jeopardize missions or cause system/ personnel damage or injury.

5. Be used to address critical issues and questions regarding manning levels and skill levels and also to provide laison/input to personnel/ training specialists.

6. Be used to address logistics; console maintainability, reliability, and repair.

7. Be used to address countermeasures in case of console failure for whatever reason.

Periodic human factors engineering reports will be furnished and will address analyses, tradeoff factors, display design parameters, checklists for system demonstrations/tests, man-machine problem areas/criteria/ recommendations.

The following references, or appropriately selected portions thereof will be used during all work, including contractual efforts, on this project:

1. Human Engineering Guide to Equipment Design, 1972, Sponsored by the Joint Army-Navy-Air Force Steering Committee.

2. Military Specification MIL-H-46855 - Human Engineering Requirements for Military Systems, Equipment and Facilities.

3. Military Standard 1472B - Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

4. Data Item DI-H-1312A - Human Factors Engineering Plan.

5. DI-H-1314 - Human Factors Engineering Progress Reports.

6. DI-H-1315 - Human Factors Engineering Final Report.

7. DI-H-1300 - Personnel and Training Requirements.
8. DI-H-1301 - Training Aids and Devices Study.
9. DI-H-1302 - New Equipment Training Plan.

PROVISION FOR OFF-LINE TEST EQUIPMENT

Admittedly, the foregoing discussion describe the conceptual design of the SMPMS as taking a heavily integrated, systems approach. However, it is important that provision be made for the employment of off-line, portable, semiautomatic test equipment which would be external to SMPMS. This external test equipment could be employed to acquire and analyze those machinery parameters that have been determined to only require monitoring on a periodic noncontinuous basis. An example of such variables would be certain machinery vibration parameters.

An effective method that could be employed to get this off-line test data into the SMPMS for further analysis would be to interface with one of the remote/local signal processing microcomputers. The interface of connection of the external test equipment to the SMPMS remote microcomputer would be via a special controlled interface, as shown in Figure 7. This special interface could take the form of the IEEE Standard 488 digital interface.[12] This is assuming, of course, that the data from the external test equipment will be in a compatible digital format.

SUPPORTING PROGRAMS, DOCUMENTATION, AND SPECIFICATIONS

This section of the report covers those programs and documents which provide guidelines and substance directed at attaining a cost-effective maintenance support and reliability assurance in Navy systems. In some cases, the support concept (e.g., testability) is new and not fully developed; nevertheless, it is hoped that the spirit and intent of the concept or document would be followed throughout the system design and development phases.

STANDARD ELECTRONIC MODULE PROGRAM

The SEM program is an effort to supply standard electronic modules throughout the Navy. The major benefits of the program are increased reliability, improved logistics, and low life-cycle costs. Through a

process of uniform environmental testing and mass production, the SEM modules exhibit a high reliability. By specifying only the function of the module, the vendor is given the liberty of using the technology of his choice in realizing the end function. This promotes vendor competition and technological advancement as well as cost reduction. The procurement of modules will not be dependent upon a particular technology or vendor, but rather upon a common logistic base, resulting in smaller inventories. All of the above factors contribute to a lower life-cycle cost and improved logistics.

The SMPM system will utilize SEM modules in its design in accordance with Naval Material Command Instruction 4120.102B. This instruction states that the SEM program will be considered on all major programs where the total estimated cost for RDT&E, prototypes, first articles, preproduction, and initial production exceeds $1 million. Reasons for not using SEM modules must be justified and the use of other electronic packaging concepts must be explained. During the course of the SMPMS design it is highly probable that special modules will have to be developed and qualified under the SEM program. Special emphasis should be placed on utilizing SEM qualified microprocessors, such as the 8-bit Intel 8080A and the Motorola 6800 and the 16-bit Hughes-developed AN/UYK-30 military microcomputer. Other microprocessors under development in the SEM program are the:

1. Intersil 6100, 12-bit CMOS.
2. Advanced Microdevices 2900.
3. Intel 3000, bipolar.
4. Zilog Z80.

Related documents pertaining to the SEM program are:

1. MIL-STD-1389 - Military Standard Design Requirements for Standard Hardware Program Electronic Modules.

2. MIL-STD-1378A - Military Standard Requirements for Employing Standard Hardware Program Modules.

3. Military Handbook 239 - Navy Standard Hardware Program Application Handbook.

4. MIL-SPEC M-28787 - Military Specification Modules, Electronic Standard Hardware Program, General Specification for.

5. MIL-STD-1634 - Military Standard, Module Descriptions for the Standard Electronic Module Program.

MONITORING SYSTEM RELIABILITY

For the SMPM system to be effective in achieving its goals, high reliability must be inherent in its design. This design requirement can best be realized by utilizing SEM modules which have demonstrated high reliability in the field and under environmental test conditions.

A quantitative reliability requirement provides a measure of failure frequency or a probability statement of system operation without a failure over a specific time period. However, reliability requirements by their very nature to not stand alone and cannot be implemented without recognizing their relationship to other related considerations as well. These other considerations are usually maintinability and availability.

A quantitative maintainability requirement provides a measure of the time required to restore the system to operational status in the event of a failure. (See the following section on Supportability.)

The result of these two requirements is availability (A). This is a measure of the time that the system is in and operational status. In actual practice, A is expressed as the fraction of the total time that the system is available for use. Then for steady-state availability[13]

$$A = \frac{\text{Uptime}}{\text{Uptime + Downtime}} \tag{1}$$

or

$$A = \frac{\text{MTBF}}{\text{MTBF + MTTR}} \tag{2}$$

As in similar shipboard electronic instrumentation systems employing a strong supportability posture, the maintainability requirement of interest should be considered to be 30-minute (0.5-hour) MTTR.[14]

The reliability requirement for the SMPMS is much more difficult to determine. Ideally, this requirement would yield the greatest mean-time-between-failure that can be afforded in a cost-effective manner. The primary difficulty is that the Navy is not developing a standard-type system

that has a forerunner in the Fleet. It is expected that the detailed reliability requirements for the monitoring system will be determined in a preliminary portion of the detailed system design process.

However, a few statements on reliability can be made. Initially, as a guideline or rule of thumb, functional redundancy will be encouraged in the monitoring system design. This redundancy would replace only four or five monitoring/processing function blocks in series and would parallel other, similar function blocks with tem to enhance the reliability.

In addition, some estimates of system availability can be made. The previously mentioned MIL-STD-1634 was consulted to obtain failure rates for 135 qualified standard electronic modules that could be employed in the design and construction of the SMPM system. The average failure rate for these 135 modules is 1.64 per million hours of operation. This translates to an average MTBF of 30,500 hours for a "naval sheltered environment" and 24,400 hours MTBF for a "naval unsheltered environment."*

As an extreme worst-case condition, it was assumed that 100 of these selected average modules could be employed in a series connection. This would yield an average system MTBF of 305 hours in a naval sheltered environment and 244 hours in a naval unsheltered environment for the 100 average modules in series.

Recalling the requirement of a mean-time-to-repair of 0.5 hours, the calculated (using Equation (2)) system availability, A, would be 0.99836 for a naval sheltered environment and 0.99796 for a naval unsheltered environment. All of these data are presented in Table 3 for easier referral.

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*Naval sheltered and naval unsheltered environments are defined in Military Standardization Handbook 217B: Reliability Prediction of Electronic Equipment (20 September 1974).

TABLE 3 - PRELIMINARY SMPMS RELIABILITY CONSIDERATIONS

	Naval Environment	
	Sheltered	Unsheltered
Average MTBF for 135 Selected SEM's (hr)	30,500	24,400
Average System MTBF for 100 Average SEM Modules in Series Connection (hr)	305	244
Required System MTTR (hr)	0.5	0.5
System Availability for the 100 Modules Series Connection	0.99836	0.99796

Failure rate data for microprocessor modules was not included in the above averages and calculations because of widely varying claims on the subject. Intel Corp. has published[15] a failure rate of eight units per 130 million hours for the 8080A microprocessor, operating in a commercial/industrial environment. Upon consulting with the standard electronic module group at the Naval Avionics Center,* Indianapolis, IN, it was learned that Intel claimed a failure rate of one per million hours of operation (MTBF = 40,000 hours, naval unsheltered) for its militarized 8080A to be employed in the SEM program. NAC, however, prefers to use a failure rate of 20 per million hours of operation (MTBF = 2000 hours, naval unsheltered) for the 8080A standard electronic module (Key Code Type HRH) until better reliability data is available for microprocessors. Although it is felt that microprocessors are inherently dependable units, improved monitoring system reliability could be realized by using redundant microprocessors in the remote data acquisition and local processing subsystems.

The preceding paragraphs have been general in their coverage, but hopefully the reader has gained some knowledge concerning the Navy's intentions for developing a reliable SMPM capability. It is desired that at the completion of the system hardware design and development (including the system built-in-test equipment and displays) the SMPM system would realize a MTBF on the order of 600 to 1000 hours. This would be in line with the capa-

*Formerly the Naval Avionics Facility, Indianapolis, IN.

bility realized for the related Surface Ship Bridge Control System development. A formal, statistically designed test of the SMPM system may be used near the end of the development phase to determine conformance to the specified reliability requirements.

SUPPORTABILITY

All monitoring system designs should incorporate the Navy's supportability policy for the specification of design requirements in contracts regarding testability/built-in-test. The general message of this policy is that supportability of equipment is best served by including maintainability/testability characteristics in the initial design before it is too late or costly for their inclusion. Important techniques that help to assure these supportability goals are stated below:

1. Synthesize a system architecture emphasizing simplicity and modularity in both software and hardware.

2. Develop a maintenance strategy in parallel with the system synthesis.

3. Make testability and maintainability two of the design parameters which are part of the system performance requirements. Ensure proper emphasis of calibration considerations.

4. From a logistic support analysis determine the need for and level of built-in-test/built-in-test equipment.

5. If built-in-test is required, synthesize built-in-test systems exploiting operational software and limiting additional BIT/BITE hardware to a maximum of 10%. Use the "Built-in-Test (BIT) Design Guide."

6. To the maximum extent practical, implement hardware designs with standard electronic modules.

7. When implementation with SEM is not possible or practical, maximize the use of readily available standard devices and promote development of system-peculiar standard card sets.

8. Exploit operational software to do system support and testing; that is to say, take greater advantage of information inherently available to the operating software for performance evaluation and diagnostic purposes.

A more complete discussion of the above techniques can be found in the report, "Effectiveness of Built-in-Test/ATE in Navy Systems."[16]

Important exploratory concepts in the area of testability are discussed in the Testability Guidance Report.[17] This report defines testability as "a characteristic of a design which allows the status (operable or inoperable) of a system or any of its subsystems to be confidently determined in a timely fashion. Design for testability (DFT) is a systematic, controlled process for incorporating testability characteristics into a design at minimum cost." One of the important recommendations of the report is that testability be defined in a numerically precise and measurable manner so that testability can become a design parameter instead of a design goal. Finally, a new military standard on testability is proposed to give guidance to contractors in establishing a DFT program, in measuring test effectiveness, and in demonstrating testability.

As already noted, an important aspect of supportability is the concept of BIT, which provides test data for the purpose of reducing maintenance time on equipment. The application of BIT results in significantly higher availability and increased system readiness at the cost slightly degraded reliability. In most cases this same test data can provide information on the operational status of the equipment. By incorporating BIT into the initial design of equipment an effective method of reducing system downtime can be realized. BIT is defined as an integral part of the system being tested. Though it may be removable from the system, BIT does not operate on a stand-alone basis. An additional level of circuitry is required to test and verify the operation of BIT.

To assist project managers and designers in their efforts to optimize the development, acquisition, and support of automatic test, monitoring, and diagnostic systems, the Naval Material Command has issued the following two documents:

1. Acquisition Planning Guide for Automatic Test, Monitoring, and Dignostic Systems and Equipment.
2. Built-in-Test Design Guide.

Another mandatory consideration is integrated logistic support planning, which strives for the total integration of logistic design, development, and acquisition with the hardware design, development, and production.

Also included is the integration of logistic resources. The Naval Material Command defines integrated logistic support as a process which identifies, in a systematic and orderly manner, the functions which must be performed in support of operation and maintenance and the resources needed to accomplish those functions. The process also requires that hardware and system design be reviewed with a view toward establishing hardware design and configuration which reduces, to the maximum practicable extent, the logistic support burden placed on the operating forces. Subsequently, each program is assigned an acquisition manager and a support manager to assure an integrated logistic support plan.

Monitoring and diagnostic testing should be performed in accordance with methods and standards contained in MIL-STD-1519 (Preparation of Test Requirements Document). This standard establishes the requirements for the preparation and control of the Test Requirements Documents used in specifying testing requirements for electronic subsystems. These test requirements are independent of any specific test apparatus.

Another part of the overall support program is the level of repair program plan which is established by the contractor. The purpose of LOR (Military Standard 1390B) analyses is to establish the least cost feasible repair or discard decision alternative for performing maintenance actions and to influence the equipment design in that direction.

GENERAL SPECIFICATIONS

The following military standards are listed as documents applicable to the shipboard machinery performance monitoring system development.

1. MIL-STD-1399A (Interface Standard for Shipboard Systems) - As the number and complexity of shipboard systems has increased, a corresponding need for shipboard interface standards has become apparent. Military Standard 1399A will be developed over a period of time to establish the required interface standards.

2. MIL-C-5015G (General Specification for Connectors, Electrical, Circular Threaded, AN Type) - This specification applies to circular connectors for use in electronic, electrical power, and control circuits.

3. MIL-STD-1345A (Data, Measurement, in Support of Maintenance, Calibration, and Repair of Electronic Equipment) - This standard

establishes the information requirements for maintenance support, calibration, and repair of electronic equipment.

4. MIL-STD-1605 (Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships)) - This standard provides detailed procedures for conducting an electromagnetic interference survey aboard surface ships. An EMI survey is required for new construction ships and ships receiving overhauls or other major repair work that changes the electromagnetic configuration.

5. MIL-E-16400G (NAVY) (General Specification for Electronic Interior Communication and Navigation Equipment, Naval Ship and Shore) - This specification covers the general requirements applicable to the design and construction of electronic, interior communication and navigation equipment intended for naval ship or shore applications. This specification defines the environmental conditions within which equipment must operate satisfactorily and reliably; the process for selection and application of general material and parts; and the means by which equipment as a whole will be tested to determine whether it is acceptable to the Navy.

A Test and Evaluation Master Plan will have to be developed for the testing of the SMPMS hardware to be installed at the Naval Ship Engineering Center, Philadelphia Division. This test plan must be coordinated with the output of the machinery failure detection technology phase of the SMPMS program.

CONCLUSIONS

The purpose of this report has been to convey to the reader the concept of a shipboard machinery performance monitoring capability for naval surface ships. The report has established the guidelines, intentions, and direction for the development of this monitoring capability. No attempt has been made to fix any particular system hardware design.

The actual system design for the SMPMS will be conducted during the advanced development program phase (S0359-SL). During this design phase, the system central computer/processor will be selected and a monitoring system hardware package will be developed along with the necessary system software package and information-transfer protocols. The prototype SMPMS will be demonstrated at a land-based test site, and possibly also aboard ship.

The final products from this phase of the capability development will be a monitoring system design handbook and the standard data management and analysis computer program libraries.

Detailed technical conclusions that have been derived from the concept design study that spawned this report are listed below:

1. Microcomputers are good, reliable devices and will be used extensively in the design of the SMPMS. In fact, it is believed that microcomputers are the key elements for implementing a cost-effective on-line monitoring/automatic test capability.

2. There are many benefits to be derived from a distributed-monitoring, instrumentation system. Some of these advantages are:

a. Modularity, with its benefits of smaller manageable tasks, reduced software development costs/time, easier fault identification and maintainability.

b. Redundancy and its associated improvement in system availability.

c. Automatic subsystem reconfiguration in the event of an unidentified failure.

d. Capability of dedicating a microcomputer to SMPMS subsystems fault detection and diagnosis.

3. SEM modules will be employed in the design of the SMPMS, where it is cost effective, to gain their inherent benefits of reliability, logistics, and low life-cycle costs.

4. Early consideration will be made for SMPMS supportability in its design in accordance with Naval Material Command's Supportability Policy No. 1.

5. SMPMS will include its own self-test capability to ensure human operator confidence. Whereever there exists a computer (micro or mini) based system, a continuous self-test should be employed by utilizing some portion of memory and instruction cycle time to check the basic instruction set, internal data paths, memory, and other components.

6. Emphasis will be placed in the design and development of the SMPMS on the enhancement of the human operator monitoring system interfaces (i.e., displays). The design will emphasize "user friendliness" to promote user/operator acceptance. This concept also emphasizes the

requirement for operator training capability at the SMPMS' Engineering Maintenance Center main console.

7. At present there is a need for a state-of-the-art standard (or specification) delineating test interface requirements for Navy operational systems.

8. The SMPMS must accomplish its monitoring objectives utilizing the minimum number of sensors and transducers. The maximum amount of diagnostic information must be obtained for the minimum number of monitoring system inputs.

9. The SMPMS will be designed such that any malfunction within itself will not affect the normal operation of any of the ship's machinery control systems or any of the ship's propulsion and auxiliary machinery.

APPENDIX A

REQUIREMENT FOR A MILITARY STANDARD FOR SHIPBOARD MONITORING

Currently, there is only one military standard which is approved as a guide in the monitoring of Navy operational systems. This is Military Standard 1326 (NAVY) of 15 January 1968; Test Points, Test Point Selection and Interface Requirements for Equipments Monitored by Shipboard On-Line Automatic Test Equipment. This standard was revised as of 1 April 1969. Since this standard does not address the problem of built-in-test for digital systems and other more current, necessary topics, an improved military standard is being prepared under Naval Material Command (MAT 04T) auspices.

This improved document has been preliminarily designated as Military Standard 1326A: Test Point, Built-in-Test and Test Interface Requirements for Navy Operational Systems. This standard is currently only in draft form and has not yet been approved for general use.

The purpose of this proposed standard is to establish the requirements for providing test points, built-in-test, and test interfaces to external monitoring automatic test equipment. It will provide criteria for guidance in test-point selection and defines interface and data requirements, test-point data generation, and procedures for documenting the selection of these test points.

It is well recognized that the proper performance of shipboard equipment, especially machinery, is critically dependent on good maintenance procedures. Test points, test interfaces to external ATE and internal monitoring BIT, and test logic plans are essential elements in the maintenance program and should be considered in the prime equipment design phase.

The objectives of this proposed standard include the following:

1. To achieve optimum selection and placement of test and test signal injection points for:

   a. Continuously monitoring the performance of prime equipment.

   b. Indicating the existence of a failure.

   c. Facilitating rapid isolation of a failure to the line replaceable unit to effect repair by substitution of a spare, performance of realignment, etc.

d. Facilitating failure prediction.

2. To require adequate built-in-test equipment in the prime equipment so that general system status may be continuously monitored and test-point data made easily available to maintenance personnel.

3. To require an adequate level of planning and development of test logic design along with the definition of test-point signals and their dimensions that must be provided for automatic monitoring, both internally by means of BITE and by means of external ATE.

4. To require the inclusion of a multiplexing and data bussing plan, which, along with analog-to-digital circuitry, will present a standard digital interface to external ATE.

In its course of preparation, a draft of the proposed standard was distributed to the testing community, both Navy and industry. After review of the draft was completed, constructive comments were received. It was suggested that the draft of proposed Military Standard 1326A be revised to better cover shipboard operational readiness and performance monitoring system requirements such as:

1. The proposed standard should include an overall shipboard system testing, operational readiness and performance monitoring philosophy that will result in the proper degree of BITE in new development hardware.

2. The proposed standard should define which of the standard interfaces included are mandatory. If the designer chooses to bring out analog or digital signals, what is the analog/digital interface?

3. The proposed standard should define the interface requirements between internal BITE and external functions such as general purpose electronic test equipment, operational readiness monitoring, systems' performance monitoring, and so forth.

4. A clarification of the definition passive sensor is required due to the desire to encourage standard digital interfaces.[18]

Even though the draft of proposed Military Standard 1326A is not complete, still it provides much state-of-the-art guidance and information for performance monitoring. This is a document that the Navy's steering group for shipboard machinery performance monitoring can unofficially apply on an ad hoc basis, as needed. If MIL-STD-1326A or a similar standard should be approved, it will be a major influence on the SMPMS development.

APPENDIX B

OPERATIONAL READINESS MONITORING CONSIDERATIONS AND INTERFACE WITH SHIP'S COMMAND

BACKGROUND

The lack of timely ship systems readiness information on existing platforms on a real-time basis to the ship's command (supervisory and watch personnel) has been identified as a major problem affecting Fleet operations. The reaction time to detect, evaluate, and engage an enemy threat has become significantly smaller due to the high performance of present day and near future weapon systems. This minimum reaction time requires more complex systems, a higher degree of automation, and continuous optimum system performance and readiness. This high degree of system operational readiness requires that the ship's command must have a means to rapidly assess the ship's operational readiness status. To provide a means, the Navy is conducting a development effort to define and prove the ORMS concept.[3]

In the development of the ORMS concept, it is deemed quite important to provide the commanding officer with a means for assessing the ship's operational readiness in the area of propulsion and machinery systems even though this assessment task would not, however, be directly performed by ORMS. Instead, it was planned that the SMPMS would interface with ORMS to provide to the CO that assessment of the status and capability of the propulsion and machinery systems. A discussion of that assessment interface with ORMS is appropriate to this report and is given in the following sections.

PURPOSE

To better grasp the purpose of ORMS, it is necessary for the reader to clearly understand the meaning of operational readiness. The term operational readiness has been defined to be,[19] "The capability of a unit, ship, weapons system or equipment to perform the missions or functions for which it is organized or designed. May be used in a general sense or to express a level or degree of readiness."

The definition of operationally ready is:

1. As applied to a unit, ship or weapon system - Capable of performing the missions or functions for which organized or designed. Incorporates both equipment readiness and personnel readiness.

2. As applied to personnel - Available and qualified to perform assigned missions or functions.

3. As applied to equipment - Available and in condition for serving the functions for which designed.

The term combat readiness and operational readiness are synonymous when used with respect to missions or functions performed in combat.

The objective of ORMS is the presentation of command-level operational readiness assessments in sufficient detail to enable the OOD and watch officers (EOOW, CWO, CICWO, weapons officer, and DCA) to fulfill their duties and responsibilities as delineated in Navy Weapons Procedures and U. S. Navy Regulations. Such a system is not intended to be a centralized maintenance facility to perform fault location or diagnostics upon shipboard systems and equipments. By reducing the test-point monitoring load from the 50-200 sensors per equipment required for fault localization to the 5-20 sensors per system for operational status monitoring, the ORMS concept will avoid the complexity and cost of past centralized test systems. The ORMS and SMPMS concepts employ a distributed test systems approach utilizing inexpensive microcomputers.

DESCRIPTION OF POTENTIAL ORMS FUNCTIONS

A brief summary of planned ORMS functions are included below. This list[20] of functions to be addressed by ORMS is, or course, subject to modifications as a result of progress and/or developments in the ORMS program. Figure B-1 shows the usual operational readiness reporting structure for a typical ship.[21]

Ship System Status Monitoring

This function is the most basic ORMS function, and is the principal reason for ORMS to exist. It involves the collection, processing, and storage of data from all electronic, weapons, and engineering systems which are essential to the ship's capability to carry out intended or assigned

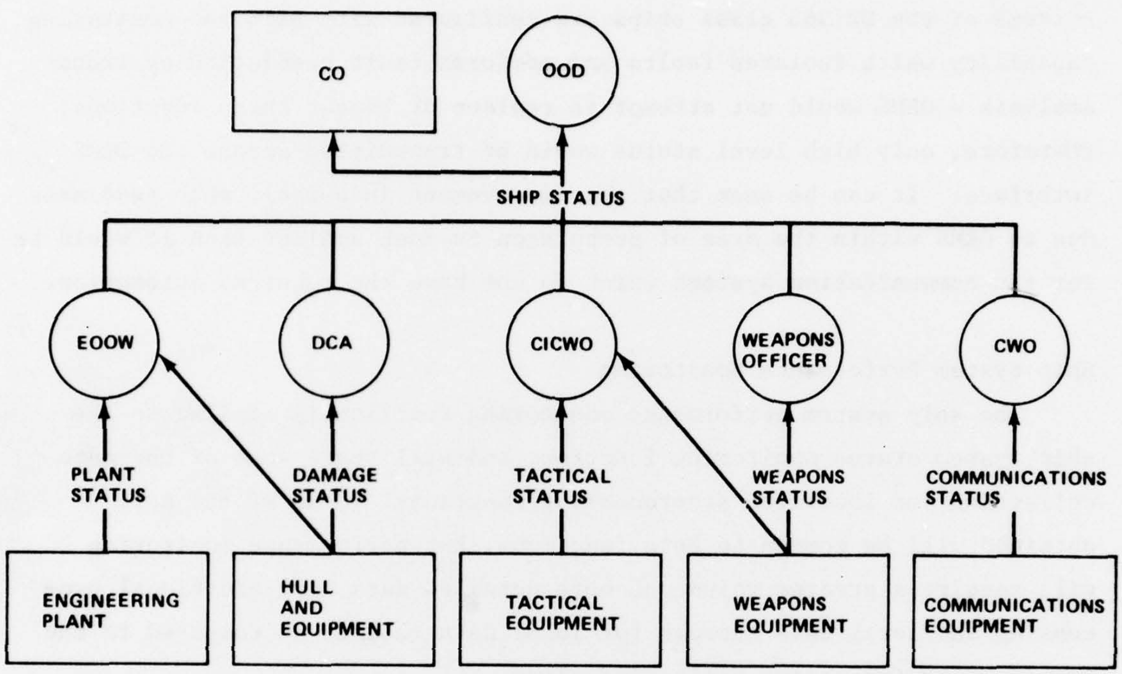

Figure B-1 - Operational Readiness Reporting Structure for a Typical Ship

missions. The resulting status data are then displayed or made available for rapid, selective display to the commanding officer, and other cognizant levels of command. Essential information thus will be available continuously or very quickly to assist in making rapid, accurate, and effective operational command decisions.

Within the system status monitoring concept for future ships, each system or component must be examined individually to determine, first, whether automatic monitoring is required, and if required, what parameters should be collected for ORMS data base. If monitoring is required, the ORMS area microprocessor will, in most instances, be interfaced with the system BITE to transfer the selected parameters for storage and display. ORMS capability will be compared to the functions performed by the system's BITE to determine specifically what processing ORMS should perform on the available measured parameters to enhance the logistic and reporting

requirements for that system within the ship. For example, the propulsion systems of the DD 963 class ships are configured with BITE and monitoring capability which isolates faults and performs fault prediction by trend analysis - ORMS would not attempt to replace or repeat these functions; therefore, only high level status would be transmitted across the ORMS interface. It can be seen that the improvement in overall ship readiness due to ORMS within the area of propulsion is much smaller than it would be for the communication systems which do not have the required automation.

Ship System Performance Monitoring

The ship system performance monitoring function is similar to the ship system status monitoring function, and will share some of the data collection and localized preprocessing functions. Some of the data obtained will be common to both functions, but performance monitoring will require a greater volume of more detailed data with additional processing and local data storage for local data readout as compared to the requirements for status monitoring alone.

The key to performance monitoring is the use of algorithms and other forms of processing on key parameters taken by the system status monitoring devices to present measures of the system or systems capabilities to command. For example, the radar maintenance people are concerned about the klystron current, frequency, and power supply voltage remaining within proper limits - and these are measurements taken in the context of status; but the tactical action officer or CO would be interested in his radar coverage range for low flying aircraft - a performance or capability measurement. To obtain the latter parameter of performance ORMS development must devise an algorithm using the status measurements and perhaps add some environmental data if possible to determine ducting characteristics. This type of processing applies to many other systems aboard the ship. The cost of implementing the function once the status monitoring has been implemented is maybe 3 to 5 percent of the total system cost and the improvement in readiness assessment of missions by the CO is sharply improved.

Data collected for performance monitoring will generally be preprocessed to minimize the data to be conveyed over the data transmission

medium. Preprocessing performance monitoring data will include comparison with present limits, and the activation of suitable alarms when these limits are exceeded. A direct display of the measured values will be selectable at any time for comparison with normal values and evaluation of equipment performance by appropriate personnel.

Performance monitoring will:

1. Provide up-to-date performance information for all monitored equipments and systems virtually continuously.
2. Call attention to degradations in performance almost instantly.
3. Relieve manpower requirements to a degree.
4. Shorten the time to recognize the need for corrective maintenance.
5. Provide some degree of anticipation and prediction of the need for maintenance.
6. Increase the accuracy of equipment performance assessments.
7. Reduce direct human effort in measuring and monitoring equipment.

Mission Readiness Assessment

This function is visualized as a presentation of exception data taken from the status and performance monitoring functions. For example, the CO might wish to determine his capability to performa a mission which requires rapid steaming for 2 days and then a careful surface search for survivors. Data could be selected automatically for him from the propulsion and radar parameters that would give him his range at various speeds, his maximum speed capability, and his surface search radar range for the type object of his search.

The data planned for mission readiness assessment are the highest level summary data planned for ORMS and are an assessment of the ship's limitations taken from the ship system status and performance monitoring functions for those systems which are required to perform specific mission tasks.

Fault Prediction

The planned fault prediction function in ORMS will analyze recorded measured values of selected monitored parameters and provide an indication to the crew of an impending failure. This impending failure information

can be important to both maintenance personnel and to command as an indication of equipments' future state of readiness.

The methodology planned for predicting failures or problems is to maintain a historical file of key system measurements along with allowable limits to ensure that the measurement is not only within limits, but remaining stable under like conditions. This type of trend analysis should given early warning that a system parameter is approaching and unacceptable value, is fluctuating where it had always remained stable, or perhaps has changed from a previous stable value to a new one without explanation. This form of automatic diagnostics can be of great value in early detection of incipient failure caused by gradual component degradation. Catastrophic rapid failures will of course not be predicted.

Ship Systems Configuration Management

This function provides the means of indicating in real-time the configuration of all systems containing sufficient redundancy to permit interchanges of equipment configuration. Such systems include communications, electrical power generation and distribution, freshwater distillation, water line distribution and pressurization, heating, and air conditioning equipment, radar display and data utilization, remote weapon fire control, etc. The ships systems configuration function impacts a variety of electric, hull, machinery, and electrical systems on typical Navy platforms.

Automated PMS

Utilizing standard data base techniques, this technique provides for storage and retrieval of a complete cycle PMS schedule for a ship. Using standard sorting techniques, quarterly schedules may be generated for each department and for each work center at a considerable reduction of manual recording by work center supervisors.

Automated Material Control System

The automated material control system would utilize standard data base techniques and provide for storage and retrieval of data relative to ship's supplies and ship's record.

It is anticipated that these functions, to be incorporated in an Operational Readiness Monitoring System, will receive the needed information concerning the ship's propulsion and auxiliary machinery systems from the SMPMS. In this manner, the SMPMS and ORMS will complement each other; neither will attempt to supplant the other. Each must provide specific information to the ship's management, but the information will be tailored by each system so as to be appropriate for the internal level of responsibility that will utilize such knowledge.

ORMS ARCHITECTURE

The SMPMS conceptual design addresses the ORMS architecture because both ORMS and SMPM have similar operational requirements. Basic to both architectures, ORMS and SMPMS consist of microprocessor based data acquisition and processing system, SDMS transmission of data, and processing and display systems. Allowing for such differences as the quantity of test-point data acquired by SMPMS and application software, ORMS provides useful guidelines in the conceptual design of SMPMS.

The Naval Ocean Systems Center, San Diego, CA (formerly the Naval Electronics Laboratory Center), determined that the hierarchical, watch-centered configuration of the ORMS system was the best candidate for use on ships with SDMS as well as on those without SDMS. A block diagram of the watch-centered system is shown in Figure B-2. In this discussion, it is assumed that SDMS is the standard bus for routing electronic signals throughout the ship.

Input signals to the ORMS system can come from either the subsystems' sensors or BITE. In the case of BITE, the monitoring equipment is built into the subsystem by the manufacturer. BITE output signals are conditioned and converted to a digital format acceptable to the SDMS bus. With the exception of formatted BITE data, all input data are collected by microprocessors which perform data evaluation and format processing. Each of the lower level microprocessors are located next to the equipment being monitored, thus allowing a functional unity which is of great benefit in maintenance and troubleshooting. By processing the data at the lower levels, less data need be forwarded to the display processors, thus reducing the traffic burden on SDMS.

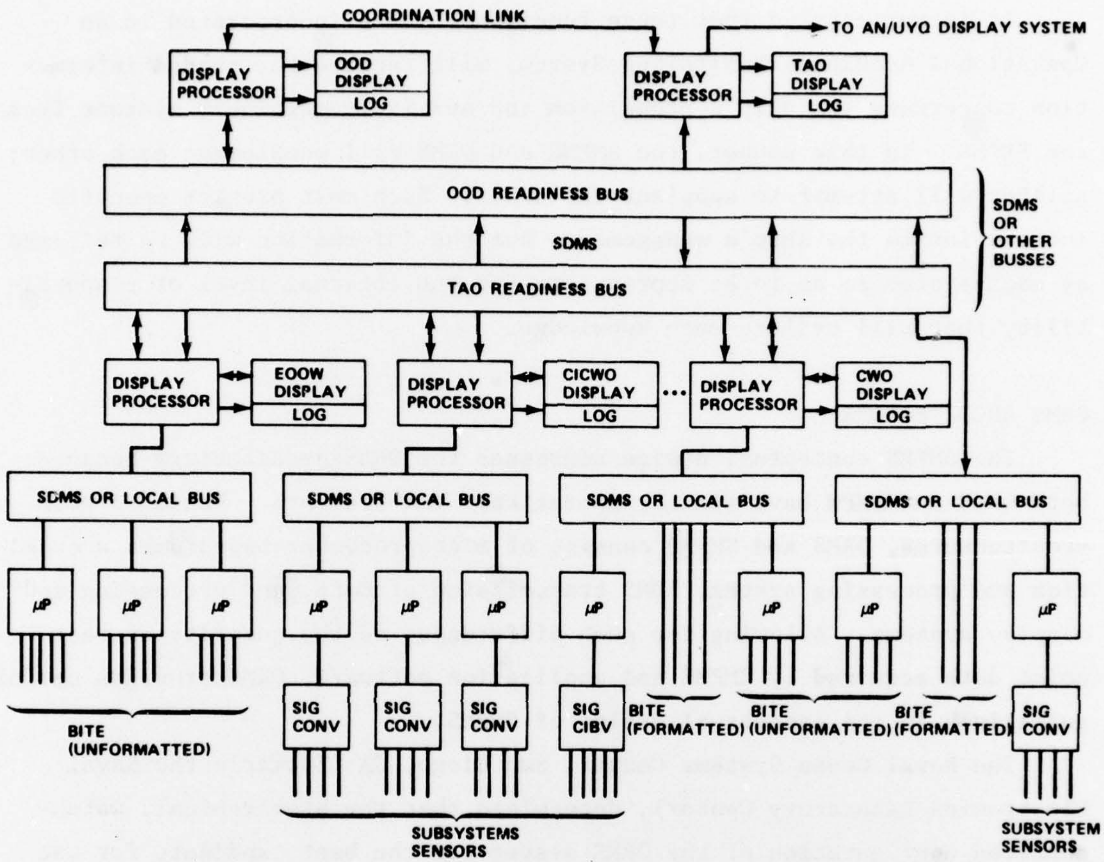

Figure B-2 - ORMS Hierarchical Watch-Centered System

The display processors in the various watch areas perform the functions of display, decision, and forwarding data which are of current interest to the top-level command centers such as the OOD and TAO. Each display processor is dedicated to the particular watch station, thus providing functional isolation with its benefits of survivability and ease of maintenance and fault diagnosis. Additionally, minor changes or upgrading of local subsystems may be effected with minimum impact on higher level equipment.

APPENDIX C

ORMS MONITORING TASKS THAT COULD BE INCLUDED IN AN SMPM SYSTEM FOR THE FFG 7 CLASS SHIP

OPERATIONAL STATUS

Electric Power Generation

- Ship service diesel generators 1 through 4
- Battery
- Central control station
- Lube oil system
- Seawater system
- Electrical power distribution
- Switchboards (ac)
- DC distribution
- Lighting
- Conversion equipment
- Emergency power
- Miscellaneous power generation

Propulsion System

- Gas turbine* (starboard)
- Gas turbine* (port)
- Reduction gear
- Propulsion shafting
- Controllable pitch propeller
- Accessory equipment
- Auxiliary propulsors (port and starboard)
- Control systems

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*An expanded list of gas turbine parameters to be monitored is found in Appendix B.

Countermeasures

Degaussing

Prairie air

Auxiliary Systems

Heating

Auxiliary steam

Ventilation

Air conditioning

Refrigeration

Plumbing/sewage

Fire main

Drain system

Freshwater

Fuel filling and transfer

Compressed air service

Seawater

Distilling

Steering and ship control

Deck machinery

Boat handling and stowage

Fire-Fighting Systems

Dewatering Systems

OPERATIONAL PARAMETERS

Speed

Ordered

Actual

Shaft revolutions

Propeller pitch

Casualty limits

Maintenance limits

Maximum available

Maximum expected

Time to maximum

Endurance

Fuel supply

Water supply

Lube oil supply

Fuel received

Fuel expended

Water received

Water distilled

Water expended

Lube oil received

Lube oil expended

Propulsion Capabilities

Short time

Sustained periods

Speed restrictions due to casualties

Deck Systems

Anchor Machinery Status

Roll and Pitch (Degree and Period)

Cavitation Status

Engine Smoke Status

Operating/Disabling Maintenance

Scheduled/unscheduled

Effect on system performance

Effect on ship performance

Secondary effects

Time to repair

Parts needed/available

Schedule priority

Postrepair testing

APPENDIX D

LM 2500 GAS TURBINE CONDITION AND PERFORMANCE MONITORING TASKS THAT COULD BE INCLUDED IN AN SMPM SYSTEM

LUBE SYSTEM PARAMETERS

Lube Oil Differential Pressure

- Supply filter
- Scavenge filter

Lube Oil Pressure

- Sump A
- Sump B
- Sump C
- Sump D
- Gearbox
- Vent system

Lube Oil Temperature

- Supply
- Total scavenge
- Sump A scavenge
- Sump B scavenge
- Sump C scavenge
- Sump D scavenge
- Accessory gearbox, scavenge

Lube Oil Flow

- Supply

Lube Oil Contamination

- Scatter
- Attenuation
- Conductive A sump
- Conductive B sump

Conductive C sump

Conductive D sump

Conductive, accessory gearbox

Lube Oil Quantity

Tank

FUEL SYSTEM PARAMETERS

Differential Pressure

Fuel filter

Pressure

Fuel manifold

Temperature

Fuel supply

GAS TURBINE AEROTHERMODYNAMIC PARAMETERS

Inlet

Total temperature

Statis pressure

Compressor Discharge

Total discharge

Static pressure

High-Pressure Turbine

Exhaust gas, total temperature, average

Exhaust total pressure

Power Turbine Discharge

Total temperature

Total pressure

Speed

Gas generator

Power turbine

Main Fuel Flow

Variable Stator Vane Position

Air Bleed Flow

Power Level Angle

Stage 1 High-Pressure Turbine

Average blade temperature

Peak blade temperature

Average peak blade temperature

VIBRATION PARAMETERS

Acceleration

No. 3 bearing, vertical

No. 3 bearing, horizontal

No. 4 bearing, vertical

No. 4 bearing, horizontal

Nos. 5 and 6 bearings, vertical

Nos. 5 and 6 bearings, horizontal

No. 7 bearing, vertical

No. 7 bearing, horizontal

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